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Discussion

# The missing hydrogen ion, Part-3: Science and the human flaws that compromise it

Robert Robergs *, Bridgette O'Malley, Sam Torrens

*School of Exercise and Nutrition Sciences, Queensland University of Technology, Kelvin Grove, Queensland, 4059, Australia*

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ABSTRACT

The purpose of this research was to use a historical method and core principles from scientific philosophy to explain why mistakes were made in the development of the lactic acidosis construct. On a broader scope, this research explains what science is, why some scientists despite good intention, often get it wrong, and why it takes so long (decades) to correct these errors. Science is a human behaviour that consists of the identification of a problem based on the correct application of prior knowledge, the development of a method to best resolve or test the problem, completion of these methods to acquire results, and then a correct interpretation of the results. If these steps are done correctly there is an increased probability (no guarantee) that the outcome is likely to be correct. Thomas Kuhn proposed that you can understand what science is from how it has been performed, and from his essays he revealed a very dysfunctional form of science that he called 'normal' (due the preponderance of its presence) science. Conversely, Karl Popper was adamant that the practice of 'normal' science revealed numerous flaws that deviate from fundamental principles that makes science, science. Collectively, the evidence reveals that within the sports medicine and health sciences, as with all disciplines, errors in science are more frequent than you might expect. There is an urgent need to improve how we educate and train scientists to prevent the pursuit of 'normal' science and the harm it imparts on humanity.

## 1. Introduction

In Parts-1 and -2 of this series,[1,2] evidence was presented proving that cells do not produce metabolic acids. Rather, cellular and systemic hydrogen ion ($H^+$) exchange occurs based on a combination of covalent release or attachment of $H^+$, and the pH dependent $H^+$ association or dissociation for any given ionized acid functional group during chemical reactions. Consequently, there has been historical bias and error in supporting the cellular production of metabolic acids as the cause of acidosis (e.g., lactic acid [HLa] and ketone bodies resulting in $H^+$ dissociation, which in turn causes conditions of lactic acidosis and keto-acidosis, respectively). Consequently, the content of this manuscript series presents a persuasive evidence-based narrative that an entire field of biochemistry that involves the understanding of acid-base conditions in biological systems has been misunderstood, with the unintentional perpetuation of misinformation through generations of education, research, and commentary.

This error in knowledge has occurred despite evidence against the construct of the cellular production of metabolic acids as early as 1977,[3–6] with more recent evidence-based critical research and commentary extending to current time.[7–12] If you have read Parts-1 and -2 of this series,[1,2] you could be asking yourself questions about how these mistakes could happen in science. Isn't science meant to be perfect? Why do errors occur in science? How can errors be caused and reinforced for decades within scientific disciplines despite evidence existing to refute the accepted theory for a near equivalent time-period? Are such errors rare or common within scientific disciplines? What can be done to minimize these errors?

The purpose of this final part of the series is to extend the lessons learned from the HLa construct to explain the historical development of science. Within this approach explanations will be provided for defining what science is and reveal all the reasons why there have and always will be components of scientific research that are compromised by major errors within the human pursuit of science across all disciplines. As will be explained in this final instalment, this isn't the fault of science; it is the fault of how science can too often be pursued incorrectly, even despite concerted efforts to do the best job possible. Such human infused imperfections to the pursuit of science cause dire consequences to the lost opportunities to the advancement of knowledge that then result.

* Corresponding author. School of Exercise and Nutrition Sciences, O Block, A Wing, Level 4, Room A420, Faculty of Health, Queensland University of Technology, Kelvin Grove, Queensland, 4059, Australia.

*E-mail address:* rob.robergs@qut.edu.au (R. Robergs).

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**Abbreviations**

| | |
|---|---|
| $H^+$ | Hydrogen ion = hydrogen atom that is missing its single electron (also termed a proton) |
| pH | Measurement scale of acidity-alkalinity, ranging from 1 to 14 |
| HLa | Lactic acid |
| La | Lactate |

Understanding these realities in the landscape of the human pursuit of science is the start to decreasing the incidence and magnitude of such errors and thereby improve the benefits of science to humanity. Core to this endeavour is the intent to assist students in their journey to becoming the best scientific researcher they can be. For pre-existing research scientists, the content may encourage them to re-evaluate what type of scientist they are ('normal' vs. 'extraordinary'; definitions to come later) and have the potential to redirect their journey in science to ensure their legacy to their disciplines, students and society is one that has a long-lasting positive impact. Once again, this content will be structured, where suited, by a mix of pertinent questions, common views, evidence, and answers.

## 2. Question 1: What is science?

***Common View:*** Science involves structured inquiry framed around one or more research questions that lead to methodologies that increase the likelihood that the results obtained reveal a correct (truth) answer and/or interpretation. While different questions require different research (scientific) methodologies, a core method to science is the randomized control group design, also often called a 'clinical trial'.

***Evidence:*** The Common View presented is largely correct but requires considerable clarification, as will be provided in this section. Regardless, if you asked this question to 100 PhD qualified scientists, you might get just as many different answers. The reality is this; science remains a work in progress, which also implies that the definition of science and how it is practiced are also evolving. Central to this dilemma in current time is the fact that most scientists are poorly educated on the topic of what science is; the issue has never been a topic of well-structured, more advanced learning during the education and training of scientists. Yes, this issue is a large part of the widespread problems with science today.

It is also important to clarify how the pursuit of science may not be science, regardless of the quality of the research design if the wrong question is asked, poor methods are used, the intent is to support and not challenge a convention, and when each of the above points are framed around an inappropriate model formed from inadequate knowledge. Despite honourable intent, harm is done when an outdated (incorrect) paradigm (theory, model, method, or data interpretation) is accepted and used to produce and/or interpret data (see Question 3). Nevertheless, the unfortunate reality is that the awareness of a correct (truth) or incorrect answer to a research problem or interpretation is not always immediately obvious. This will be reintroduced in more detail later.

### *2.1. Recent development of science*

There is not enough space in this manuscript for a detailed historical account of the development of science. For such added content, read the short texts of Lewens[13] and Okasha[14] and the hallmark (though controversial; see the following sub-topic) book by Kuhn.[15] Consequently, the question to raise and answer pertains to how has science developed in the last century and what tenants of the scientific method have been recognized as essential?

Limited commentary is available on this question in the last 50 years, however, throughout the latter half of the 20th century considerable scholarship was directed to the writings of two men and their views on the pursuit of science, Karl Popper and Thomas Kuhn. Popper wrote his initial text on numerous features for how science should be practiced in 1934,[16] and his work has made invaluable contributions to how science is pursued to current time regarding such practices as deduction, and falsification or refutation (more on that later). Despite the importance of Popper, attention will first be directed to Thomas Kuhn for his writings provide a foundation from which to better understand Popper's work, which in turn feeds back to providing an alternate interpretation of Kuhn's work.

#### *2.1.1. Thomas Kuhn: Paradigms, normal science, anomalies, rises and revolutionary change*

Thomas Kuhn's classic text, *The Structure Of Scientific Revolutions*[15] is the book most current scientists and scientific philosophers would turn to in order to understand the development of science prior to the 1960's. To begin, it is important to acknowledge that Kuhn was not a scientific philosopher. Kuhn was a physicist who became aware of his interest in the historical pursuit of science while completing his Ph.D. study and training in theoretical physics.[15] Kuhn applied this interest to the historical development of the disciplines of science he knew best, the physical sciences.

The underlying premise of Kuhn's text is that you can learn of what science is from how it is practiced. This assumption is enough to question Kuhn's approach to the topic. If Kuhn's assumption is placed in context for a crucially important topic within clinical exercise physiology, an equivalent assumption would be that the decrease in physical activity as one ages is testament to the relevance of this behaviour. This postulate, of course, is known to be incorrect due to the evidence-based need for sustained daily quality physical activity (exercise) into older age. You can apply this test to whatever human behaviour you choose (e.g., politics, democracies, banking, finance, health care, etc.) and if you do, you will soon become aware of numerous flaws in the conventional practice of all forms of human behaviour and that because of this such practice is far from ideal. Kuhn can be criticized for not being aware of this logic.

Now that the fundamental limitation of Kuhn's work is understood, it is important to realise that many of Kuhn's observations about the physical sciences revealed traits that help us to understand the core features that characterise the less-than-ideal vs. the more-ideal pursuit of science. These characteristics are presented below and are summarized in Fig. 1.

(1) A ***paradigm*** is a theory, model or broader understanding of a topic that has been accepted by a majority because it is perceived to be able to a) best solve problems in the application of the paradigm to the real or natural world, b) can verify new measurements of related phenomena (facts) through prediction from the theory or model, and c) stimulate further research inquiry to improve understanding and articulation of itself. Kuhn was inconsistent in his use of the word. However, consensus and common sense reveals that a paradigm could be a highly focussed topic, such as the best methodological approach to measure a specific variable, be broad in implications, as in whether time is a relative concept, and often exist within multi-layered disciplines or topics. As such, paradigms can be embedded within other paradigms. In either case, it is imperative to understand that a paradigm, as is the case for any theory, model, method, or data interpretation within science, must be conceptually focussed (can be expressed as a simple research question) and open to refutation. This is a positive issue.

(2) It is normal to accept a paradigm without rigorous attempts at falsification. Historically speaking, its presence is viewed as proof, regardless of how unscientific this conduct is. This is a negative issue.

(3) ***Normal science*** involves seeking answers to questions (solutions to problems) that can be formed or identified within the accepted paradigm (components a, b, and c of item 1). This work is not

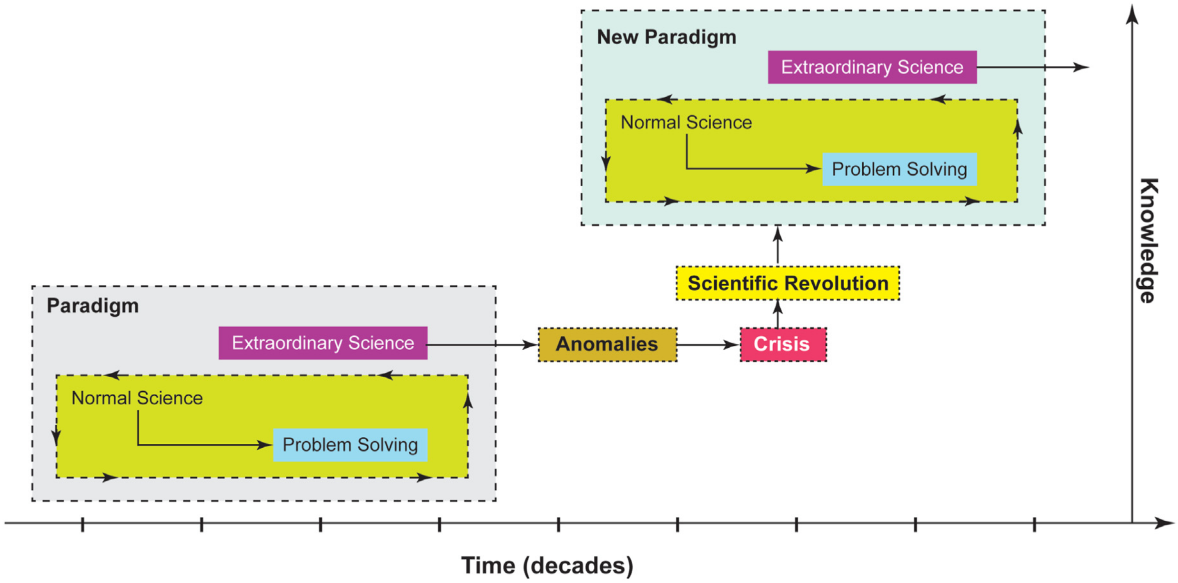


**Fig. 1.** A diagrammatic summary based on the main historical observations from Kuhn[17] for the process of the sequential transitions from normal science within a paradigm to the detection of anomalies leading to a revised or new paradigm.
If accepted, the intent is for this figure to be in colour in electronic and print versions.

critically confronting to the paradigm, but rather is a means to further refine or understand the paradigm. Kuhn also provided a clear definition or description of 'normal' science that commenced with labelling it as "*mop up work*".[15] Added clarification provided by Kuhn, which is quite damning of 'normal' science, was that it was an attempt to "*… force nature into the preformed and relatively inflexible box that the paradigm supplies. No part of the aim of normal science is to call forth new forms of phenomena; indeed those that do not fit the box are often not seen at all. Nor do scientists normally aim to invent new theories, and they are often intolerant of those invented by others.*"[15] This is a negative issue.

(4) Some scientists detect circumstances where nature violates the predicted outcomes of the paradigm. These discoveries are referred to as ***anomalies.*** This is a positive issue.
(5) Anomalies and their related new discoveries are rarely the result of one person's inquiry. There is usually an extended period of critical inquiry resulting in numerous anomalies that involve contributions from multiple scientists over many years or decades. This is a positive issue, though the time frame for the correction is a negative issue due to the harm that such delays can impart on the discipline and broader society.
(6) The detection of anomalies and the crafting of opposing theories to the pre-existing paradigm represent the transition from 'normal' science to '***extraordinary***' ***science.*** This is a positive issue.
(7) When the number of anomalies combine to make a substantial impact revealing the need for revolutionary change, as compared to minor adjustments to the paradigm, a ***crisis*** develops causing considerable 'professional insecurity'. This is a positive issue.
(8) A crisis is not enough to elicit refutation of a pre-existing paradigm. The acceptance of a known incorrect paradigm will continue until there is an alternative theory that combines with the period of anomalies and crisis to fuel a new paradigm (see next item). This is a negative issue, similar to item 5.
(9) A crisis often leads to new discoveries because it forces scientists to look at the data and related problem(s) in a different way. This can result in the development of a new paradigm, or what Kuhn referred to as a **paradigm shift.** This is a positive issue.
(10) The history of the development and pursuit of science within the physical disciplines can be generalized to other disciplines. This is not yet established, though based on current evidence it is a reasonable assumption.

#### *2.1.2. Karl Popper: science and scientists should strive to be 'extraordinary'*

The relevance and limitations of Kuhn's work is best understood when contrasted to the contributions to science made by Popper.[17,18] Popper's initial explanations for the philosophical underpinnings of science were expressed in his text, *The Logic Of Scientific Discovery*,[16] first published in 1934 in German. The book was translated to English in 1958 and published again in 1959, with added editions through to 2014. For a general introduction to the relevance of Popper's views of science in modern time, see the commentary by Katch.[19]

Popper provided a concise definition of science in his 1934 text.[16] As stated; "*A scientist, whether theorist or experimenter, puts forward statements, or systems of statements, and tests them step by step.*" For the empirical scientist, "*he* (or she) *constructs hypotheses, or systems of theories, and tests them against experience by observation and experiment.*"[16]

Perhaps the most relevant content proposed by Popper was that science demands the process of falsifiability. Popper was adamant that a core tenant of science is a method, as well as features of a proposed theory, that enables another scientist to attempt to prove the results derived from either of deductive research or a developed theory to be incorrect (falsifiable, refutable). For example, in simple explanation, it would be unscientific to argue factual interpretation if there was no way to verify its accuracy (mostly through replication and related verification). Yet Popper was wise in taking this further. It is conceivably quite easy for a researcher to design an experiment (intentionally or unintentionally) that will favour a bias. Thus, you cannot prove something based solely on evidence that support an interpretation. The most effective way to prove something is to fail at sincere attempts to prove it wrong.

While this last sentence is important, one could argue that a researcher could also design an experiment (intentionally or unintentionally) that will favour disproof. Unfortunately, Popper did not comment on this. Nevertheless, such a reciprocal reality is yet another dilemma of science, where there remains uncertainty in knowing when to ascribe 'correctness' to a method and the related data generated to enable an acceptance of the results as being most probable to being true. Presumably, over time, if results and interpretations from prior research are challenged by attempts to falsify across numerous researchers and their laboratories and alternate methodologies, eventually a more consistent result would provide clarity. This process would then lead to Kuhn's anomalies, then a crisis, and then possibly the events proceeding to a refined or alternate paradigm for that topic.

Even though it can be proposed that the concept of falsifiability has been a part of scientific endeavour through the 19th century, Popper was the first to ascribe the importance of this core trait to the more correct pursuit of science in the 20th century, along with explaining why this process was important. Yet to current time it is fair to state that falsifiability has remained an inconsistently pursued trait of science, with the practice of most modern scientific journals (perhaps due to an underlying bias towards established paradigms in peer review = 'normal' science) proving that there is little acceptance of the importance of replication and empirical evidence for disproving prior published claims. Perhaps this flaw of peer review and related functions of journal editors is to be expected based on Kuhn's own dire definition of 'normal' science and the scientists who pursue it. Yet there is a long history of concern that peer review is replete (though thankfully not in totality) with the 'normal' scientist.[20–27]

In 1965, both Kuhn and Popper were key presenters at a conference in England and the text of each contributor's presentation was collated and first published in an edited book in 1970.[28] This reading is a fascinating compilation of how each scientist viewed each other's writings and views, and Kuhn's 'normal' science label attracted considerable critical commentary.[29,30] The more important realization from this publication is how it offered insight for why Popper's falsifiability doctrine of the pursuit of science was relevant; it decreases the probability that the pursuit of science supports an incorrect paradigm.

We can first view Popper's comments of scientists who pursue Kuhn's 'normal' science. To begin, Popper recognized that the history of science, as well as the present-day pursuit of science, reveals that the 'normal' scientist is real. "… *what Kuhn has described* ('normal' science) *does exist … it is a phenomenon which I dislike (because I regard it as a danger to science) while he* (Kuhn) *apparently does not dislike it (because he regards it as 'normal')* …"[29] Popper had obviously read Kuhn's prior definitions of 'normal' science (see item 3 of the summary of Kuhn's text) and continued his explanation of his view of the 'danger' to be how; "… *the 'normal' scientist, as Kuhn describes him* (or her)*, is a person one ought to be sorry for …. has been badly taught …. in a dogmatic spirit …. a victim of indoctrination …. He* (or she) *has learned a technique without asking for the reason why. The success of the 'normal' scientist consists, entirely, in showing that the ruling theory can be properly and satisfactorily applied in order to reach a solution of the puzzle in question.*"[29] These comments by Popper are harsh, but not an exaggeration, for as previously explained they are a logical interpretation of Kuhn's own derogatory definition of 'normal' science.

Popper was not demanding that all science should be critical. Rather, his writings were based on the need for an underlying foundation of scientific inquiry that continues to challenge convention, and where, for example, inquiry framed to apply a pre-existing paradigm does so by a research design that contains within it the potential to detect anomalies. This inquiry pathway is not always easy and remains the problem that confronts all science; that at any point in time we do not know what we do not know, and as such, over time, what is accepted as true today can easily be reversed tomorrow. Added to this are further constraints imposed by instrumentation. Yet here is the benefit of Popper's wisdom, for if there is not core (rudimentary or routine) critical confrontation in the pursuit of science, then there is a risk for not detecting data that is evidence of an anomaly. This postulate forms the core of Popper's concerns for the 'danger' in an accepting, rather than critically confronting trait for the 'normal' pursuit of science.

***Answer:*** Science is not a discipline, nor is it a specific method. Science is the development and application of an approach to answer a question, or solve a problem, based on the best-available evidence and methods of the time, combined with the correct application of correct knowledge leading to evidence-based rational thinking for deciphering an answer (or solution) that is most likely to be true. The problems endemic to science are not of consequence to its definition, but to the way humans pursue science. The collective understanding of Kuhn's and Popper's explanations of how to pursue science provide what is arguably a more balanced understanding of how to educate and direct both current and future scientists in how to strive for the 'extraordinary' rather than the questionable 'normal' pursuit of science.

## 3. Question 2: Is Kuhn's 'extraordinary science' evidence of Popper's concept of falsification?

**Common View:** Yes, this statement is correct. When you carefully read Kuhn's text,[15] there is clearly a recognition that external to 'normal science' there has been repeated evidence of results from scientific research that challenge the conventional paradigm, and as explained prior, Kuhn labelled such findings as anomalies.

**Evidence and Answer:** Yes, the Common View is correct, yet the topic deserves further explanation. Popper's frustrations with the existence of 'normal' science were the constraining definition that Kuhn used, the use of the word 'normal' to label it, the infrequent occurrences of extraordinary science (which Popper would probably have preferred to be the 'normal' pursuit of science), and the period of extended delay (decades) before the development of a crisis, further delays in the eventual acceptance of the new evidence, and further delays in the accompanied development and acceptance of a new paradigm.

There is a need to add another wrinkle to this topic. What if the portrayal of new knowledge by prolonged transitions from an accepted paradigm to anomalies, then a crisis, then paradigm shift transitions (Fig. 1) are also imperfections in how humans have crafted Kuhn's 'normal' science? What would a more ideal system of scientific discovery look like? One answer is that a scientifically healthy topic of inquiry or application within a discipline would be one characterised by encouragement of evidence-based critical conjecture. Such a system would function so that the only prevailing paradigms are closer to being axioms, and in so doing, prevent premature acceptance of new paradigms. The all too frequent problem within the history of exercise physiology scientific pursuits within sports medicine and the health sciences has been the rushed acceptance of interpretations of topics to paradigms, often based on opinions being inappropriately raised to facts. When this occurs and is accompanied by a lack of critical research inquiry, such paradigms remain difficult to change.

## 4. Question 3: Does the detection of anomalies and the eventual corrections that occur reveal that the human pursuit of science is self-correcting, which means science as it is currently pursued, is working fine?

**Common View:** Given that it is likely that errors are eventually detected in the current conventional human pursuit of science ('normal' science) and corrections occur, there is no need for concern for how science is being conducted.

**Evidence and Answer:** There are two aspects of incorrect thinking and interpretation in the Common View. 1) When looking at Fig. 1 and having read Kuhn's text,[15] such corrections occur outside of 'normal' science. This is important, for it means there are some scientists who operate outside of problematic paradigms, can detect anomalies, identify added evidence (new anomalies) through other research, or their own, and perhaps struggle with opposing the inertia of the establishment to instigate a crisis. This leads to further struggle in the proposal of a new or improved paradigm (paradigm shift), and the eventual completion of the correction. Such events all contribute to the time delay in this process. 2) It is not whether there is or is not a self-correcting nature to the pursuit of science that is important. The important issue is the timeframe for this correction, as well as the damage caused throughout the duration of misunderstanding. The greater the delay, the more extreme the damage.

Given the overwhelming importance of science to humanity and the planet we live on, surely all scientists should be educated, trained, and evaluated on the quality and originality of their work, and the related time efficiency through which they can solve problems or answer questions of immediate or future relevance.

## 5. Question 4: Is it common for errors to occur in the pursuit of science, if so why, and how long does it take to correct these errors?

**Common View:** Errors occur infrequently in science, and when they do occur this is to be expected due to human error. However, the advanced status of technology and expansion of knowledge across numerous applications and disciplines around the world is testament to the "successes" of science.

**Evidence:** These are difficult questions to answer, not because the evidence is elusive, but because the evidence can often eventually be revealed to be obvious for those widely read within their discipline's paradigms, and across the history and philosophy of science.

There is a long history of commentary and research on the pursuit of science. Such an evidence-based appraisal reveals numerous flaws in scientific endeavour, regardless of how sincere such attempts were. Robergs[8–12,17,25,26] has provided evidence-based commentary of many of these errors, as has numerous research on the performance of peer review within science in decades prior.[20–24] In addition, Kagereki et al.[27] published research of the publication (or significance) bias (favouring research reporting statistical significance) for journals supporting the oral health disciplines. For the details of such scientific assessments on how science is pursued, readers are directed to the prior cited publications.

## 6. The commonality of errors in science

Considerable content has already been presented in this manuscript revealing the relatively common occurrence of errors in science.[1–31] By 'errors' the intent is not to refer to small items such as the formatting of tables or figures, grammar, improper or correct reference citations, etc. The 'errors' refer to improper methodology, flawed assumptions and/or data interpretations, an over-reliance on outdated and poorly evidence-based paradigms, etc. The difficultly in providing an accurate estimate for the prevalence and incidence of flawed science is difficult given that often the errors may not be revealed for years, or decades after the publication of the scientific manuscript. In this time-period, such errors can be reinforced by further research of other scientists that have accepted the paradigm (theory, method, data interpretation), thereby allowing other researchers to mistakenly confer the preponderance of acceptance and application as evidence of validity, which of course it is not.

### 6.1. *Kuhn's observations of the physical sciences*

Kuhn provided an interesting summary for the progressive development of select topics within the physical sciences during the 17$^{th}$ to 20$^{th}$ centuries. Once again, Kuhn's purpose was to learn about science from how it has been pursued. The result was a collection of essays, including some that directed attention to the theories of optics, electricity, x-rays, radioactivity, and oxygen[15] (chapters 1 to 7). All the topics that Kuhn focussed on were characterized by having pre-existing accepted theories and related understandings (paradigms), only to reveal scientific discoveries of anomalies to the current paradigm that fuelled major shifts in understanding and knowledge. As previously explained, Kuhn referred to these developments as 'paradigm shifts'.[15]

Rather than detail this relatively early (19$^{th}$ and early 20$^{th}$ centuries) research from the physical sciences, it is best to provide more detailed explanations for why the decades of evidence against a lactic acidosis has gained sufficient evidential proof to represent another major paradigm shift that not only affects the exercise sciences, sports medicine, and other health sciences, but also the core basic science disciplines of chemistry, biochemistry and acid-base chemistry.

### 6.2. *'Normal science' and the lactic acid construct*

Based on the prior content of this Part-3, in addition to the content of Parts-1[1] and -2,[2] it is worthwhile to reflect on the persistence of the HLa construct in the context of the work of Kuhn[15,30] and Popper.[16,29]

The non-empirical and therefore unscientific development, acceptance and reinforcement of the HLa construct to recent time raises numerous questions linked to Kuhn's and Popper's descriptions of 'normal' science. For example, if science is based on empirical findings, then why is it so difficult and why does it take so long for expansive evidence against a previously, though incorrectly accepted paradigm to accrue and instigate a paradigm shift? For HLa, this is partly explained by the very early acceptance of the nomenclature of acids prior to the elucidation of the more complex acid-base chemistry. This was further hampered by the long duration (more than 60 years) between the initial research of HLa, and indeed other acids linked to cellular metabolism, which thereby allowed their widespread acceptance and entrenchment into the epistemology of many disciplines.[9]

The more difficult questions concern more recent conduct in science when knowledge was available, and evidence of anomalies were increasing in number, yet there was sustained acceptance and application of the HLa construct. Kuhn's observation of the multiple decades needed to induce and complete a paradigm shift is clearly exemplified in the duration of the struggle to empirically challenge the HLa construct. It has now been more than 100 years since Nobel Prize research of Hill and Meyerhoff,[9] more than 45 years since the initial commentary by Gevers et al.,[3] and almost 20 years since the initial and more detailed arguments presented by Robergs et al.[9]

Such time frames are logical when you consider the inertia engrained in the education involved in training teachers and scientists, the writing of textbooks, and the transfer of this content via a new generation of academics and scientists to the next generation of students. When you then add in aspects of dysfunction in the education and training of academics and scientists (e.g., no advanced study of what science is and how scientific philosophy and the historical development of the human pursuit of science has shaped science), the bias inherent in peer review that reinforces a pursuit of Kuhn's 'normal' science rather than Kuhn's 'extraordinary' science, and the flaws of human personality and behaviour (e.g., ego, authority, notoriety, power, etc.), it is hard to comprehend that unanimous correction can happen at all. But corrections have occurred within numerous sub-disciplines of exercise physiology, with the best examples being the shifts away from supporting the nomenclature and related physiological knowledge of topics such as the oxygen debt[32,33] and the 'anaerobic' threshold.[34] Challenge and change are commonalities in the pursuit of science, but as expressed prior, why does the process need to be so tortuous and unrewarding to those who have the integrity to aspire to the 'extraordinary'?

### 6.3. *'Normal' science as an obstacle to 'extraordinary' science*

The dilemmas of the HLa construct are examples of a much larger problem; that of the likely increased incidence and prevalence of 'normal' science since 1962 to current time. Indeed, in 1963 Bernard Forscher wrote and published a metaphoric manuscript that labelled science as a brick factory fuelling a construction industry.[35] Bricks were knowledge, and the construction industry was the broader pursuit of science responsible for not only making the bricks but also the buildings (paradigms) resulting from their use. Forsher wrote the manuscript based on his concerns during the 1960's (and perhaps even earlier), for the growing dysfunction of science. Such concerns were totally consistent with the opinions of 'normal' science expressed in that time period by Kuhn[15,30] and Popper.[16,29]

In 2023, Robergs published a contemporary expansion of Forscher's metaphor.[36] Such writing was based on observations from a career in science spanning 1985 to 2023 that ‘normal’ science was not only evident today, but far more dire in its expansion of dysfunction across multiple aspects of science. Embedded within this reflection were examples of concern within the education of scientists, the deteriorating function of peer review for manuscripts and grants, the increasing focus of many scientific journals on profit and not scientific integrity, and the growing disparity in access to the completion of scientific scholarship caused by the exponentially increasing cost of open access publishing to the authors and/or their institutions.

These dysfunctions and the resilience of ‘normal’ science are disturbing. Added concern arises when it remains unclear who is responsible for the future of what science is, how it is conducted, and who should pay for and profit from its pursuit.

***Answers:*** Based on the evidence the answer is clear. Yes, major errors are common in the human pursuit of science due to a combination of the human influence, as well as the limitations imposed by deficiencies in methodology, instruments, and knowledge. For exercise physiology, which is a relatively young discipline, many errors remain from previous eras where constraints imposed by limited knowledge and instrumentation remain problematic to the epistemology of current time, and often combined with a premature (poorly evidence-based) acceptance of the paradigm. Nevertheless, numerous examples exist for paradigm shifts fuelled by detected anomalies and how such evidence has been used to propose an alternate paradigm (e.g., $O_2$ debt vs. EPOC; decreased use and acceptance of the term ‘anaerobic’ when labelling a metabolic threshold; HLa vs. lactate [$La^-$], etc.).

The major problem with these processes is the time it takes to have a correction to a flawed paradigm, which can require multiple decades. To some extent this time is understandable as the application of knowledge is not just confined to the disciplines that create it. Communicating changed understanding requires changes to education, public awareness, and application of the knowledge, and each oppose the human trait of a reluctance to change. The collective of these concerns reveals a need to minimize all components that delay paradigm shifts, for the longer the duration for a new (more correct) paradigm to become established, the more harm is done to the discipline and its impact to society.

## 7. Question 5: how can you improve the quality of your pursuit of science so that it becomes ‘extraordinary’?

***Common View:*** To succeed in science it is best to specialize within a given topic, publish within this topic as much as you can, adhere to conventions recommended within peer review, and eventually you will become established and recognized as an ‘expert’ in this field.

**Evidence and Answer:** Based on the content presented in Parts-1 to −3 of this series, the Common View is far from adequate, and more likely to compromise the quality of a scientist's pursuit of science. As was stated earlier in this manuscript, most scientists are poorly educated and mentored regarding the purpose of science and the features that define it. This is further complicated by institutional performance evaluation schemes that are based on short-term, superficial metrics that overlook the most important feature of scientific productivity, which is that of the quality of the research and its related impact to society, which of course may not occur until decades later. Einstein's $E = mc^2$ and General Theory of Relativity are perfect examples of this dilemma.[37] To the poorly trained ‘normal’ scientist,[15,16,29] the development of a career solely based on the number of publications can easily become prioritized over the quality of their scientific conduct and the associated number of paradigms they have correctly challenged or contributed to. Of course, as history shows and has been explained in this manuscript, this is never a synopsis that happens in current time. Historical relevance extended into the future is the judge of our work.

Perhaps it is best to view science to be less of a career and more of a responsibility, where the latter is more likely to nurture a research agenda more aligned to what history would eventually acknowledge as having deserved the label of ‘extraordinary’. Failing to strive for the extraordinary can only have negative outcomes connected to the increased risk for functioning within a ‘normal’ science approach, which in turn carries further risk for a scientist's work and career to be relegated to future insignificance. In many ways, as explained in the purpose, the content of this manuscript is an effort to prevent such devastating losses to the careers of many.

## 8. Recommendations

Based on this three-part series, there are clear directives to pursuing scientific inquiry that creates important new knowledge.

a) The quality of your science depends on the depth and breadth of your knowledge. The breadth is important as it informs you to be able to think differently. As such, do not over-specialize.
b) Continue to learn fundamental concepts (knowledge from disciplines that are core to numerous topics), which for exercise physiology, sports medicine and the health sciences would be organic chemistry, physics, biochemistry, bioenergetics, biophysics, and mathematics. Use this knowledge to improve your ability to detect problems and anomalies, understand their complex solutions and thereby have the confidence to challenge the conventional knowledge of your discipline.
c) Remain educated and experienced in advanced features of research design and statistics.
d) Treat all published research content as susceptible to Kuhn's ‘normal’ science, and as such, refutable.
e) Critically confront all prior published paradigms and seek to further establish their correctness, or reveal their flaws, through critically confronting scientific research.
f) When data exist from your own research, or that of others that reveal anomalies, publish this evidence. Further, use the evidence from continued anomalies to devise a revised or alternate paradigm. If the journal editorial peer review system retards this process, then complain, write to the journal editor, demand better and/or seek journals that adhere to a more ethical and respectful peer review process, or even a journal that uses a post-publication open peer review approach.
g) Read widely to ensure an awareness of alternate ways to analyse research evidence common to your discipline area.
h) Where anomalies to an accepted paradigm within your discipline are detected, write a critical review of the topic, and include a proposal of a revised paradigm that can replace the one you are challenging. Do not rely on just one manuscript to document this. Continue to publish on the topic to create the interest needed in other scientists to challenge your revised paradigm. If such challenge occurs that confirms your paradigm (mostly based on failed attempts to disprove it), that is the developing proof that is needed to establish the needed paradigm shift. Be patient, as this takes a long time and is likely to extend beyond your own career. This should not matter, for the purpose of a scientist is to serve humanity and not themself.
i) If you are an editor of a scientific journal, ensure the journal incorporates operational procedures that align to these directives.
j) If you are an administrator of a university, or a politician responsible for overseeing higher education, change your performance metrics and related reward systems so that quality (unbiased) peer review is a recognized feature of academic work. Build systems that reward real innovation and critical science, and ensure internal funding is made available to nurture ‘extraordinary’ science, which, by definition, may be too challenging to a peer review or grant review system embedded in incorrect paradigms.

## 9. Conclusions

The history of science is replete with errors concerning the premature acceptance of incorrect paradigms (previously accepted explanations of evidence, or the development of theories, pertinent to a discipline that are incorrect). Kuhn presented numerous examples from within the physical sciences and added examples from within exercise physiology have been presented in this manuscript. Such flaws in science can result from the all too often incorrect manner that science is pursued by humans. Despite their different view of science, the combined scholarship of Thomas Kuhn[15,20] and Karl Popper[16,29] provide direction in how to understand the more idealistic pursuit of science in contemporary times. Core to such an idealistic pursuit of science are persistent efforts to improve knowledge by critically confronting pre-existing paradigms, identifying the traits of Kuhn's 'normal' science within your own career and to do your best to remove them, and in so doing base your own experimental research design on a doctrine of falsifiability. If you do this correctly, you are more likely to have your pursuit of science rise to the status of Kuhn's 'extraordinary' label involving the evidence-based development of revised or new paradigms, as opposed to supporting pre-existing but incorrect paradigms.

## Ethical approval statement

This manuscript did not involve data collection from human subjects or animals and as such is exempt from such review and approval.

## Authors' contributions

**Robert Robergs:** Writing – review & editing, Writing – original draft, Resources, Methodology, Conceptualization. **Bridgette O'Malley:** Writing – review & editing, Writing – original draft, Conceptualization. **Sam Torrens:** Writing – review & editing, Writing – original draft, Conceptualization.

## Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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