Immunity for non-experts: a philbio proposal

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Abstract
I propose a conceptual framework aimed at non-expert understanding of immunity and the immune system. Such an account is needed, to replace the prevailing public view that human immune systems can be evaluated in terms of "strong" vs. "weak" defenses against disease. While accessible to common-sense, the prevailing view encourages misunderstanding, contributes to pressing social problems, and is incompatible with our best current scientific and philosophical understanding of immunity. Building on my earlier work on context-dependent understanding, I motivate a new conceptual framework for non-expert understanding of immunity that is accessible to non-experts (i.e., non-technical), engages and respects everyday experience, addresses concerns about bodily autonomy and control, and reflects our best scientific and philosophical theories about immunity and the immune system. Importantly, this conceptual approach treats non-expert understanding as epistemically beneficial in its own right, arising from a two-way mutualistic relation between expert and non-expert perspectives. The result is a simple conceptual framework consisting of three core ideas: immunity is yours, efficient, and specific (YES). The YES schema is compatible with current insights from theoretical immunology and can help address current social problems associated with vaccine skepticism and hesitancy. I conclude with some implications of this view for recent philosophical accounts of understanding.

1. Introduction

This paper offers a simple account of biological immunity for non-experts. By "non-expert," I mean anyone untrained in immunology and/or related scientific fields such as microbiology, virology, and hematology – i.e., most people, including most readers of this journal. As biological immunity is in the first instance a scientific concept, the idea of "non-expert understanding" of same may seem inappropriate; scientific concepts are understood in a scientific way or not at all. However, I shall argue, there are reasons to reject that initially plausible view. Non-expert understanding of immunity and the immune system is not only

cogent but desirable for epistemic and practical reasons. My argument, in brief, is as follows. Everyday notions of immunity and the immune system are already widespread, but those ideas are confused and misleading. For example, advice and advertisements touting ways to "strengthen" or "boost" one's immune system are very common in the US. Such "strengthening" is often associated with ideas about natural, healthy living. It's a very short step from such associations to the view that vaccines are an unnatural, poorer substitute for a naturally strong immune system. That inference is easy to make and, absent any antecedent understanding of the immune system and how it works, reasonable. These misleading conceptions of immunity are further bolstered by ideas about immune defense, strength, and control that are prevalent in science and everyday life. A number of theoretical immunologists, philosophers of science, anthropologists, and sociologists, have convincingly argued that the latter are misleading and contradicted by our best current immunology.[1] However, ameliorating the problems for non-expert conceptions of immunity poses distinct challenges. The misleading "strong vs. weak" characterization is simple and easy to understand, while our best scientific accounts of immunity (even very introductory presentations thereof) are complex and technical. It is unreasonable to expect non-experts in immunology to engage those technical accounts; not doing so is not an epistemic failure. We are all non-experts about most things. To address the problem of "immunity for non-experts," this paper offers a simple, accessible schema for understanding immunity that is neither misleading nor encouraging of vaccine hesitancy and skepticism.

Most philosophy of immunology is, understandably, focused on the science rather than its public reception and broader social impact.[2] But issues of non-expert understanding are very

[1] See Section 2 for details and references.
[2] Some major works in philosophy of immunology are reviewed in Pradeu (2019) and Swiatczak and Tauber (2020). As noted, a number of these are deeply critical of the traditional "defense"

salient in this area. Biomedicine in general is ripe for "socially-engaged philosophy of science" approaches. This paper makes that connection explicit, showing how insights from philosophy of immunology can be brought to bear on a pressing social problem. I do this in two stages. First, I reprise a key insight from recent philosophy of immunology: the "extended view of immunity." I take the latter to be the consensus view on immunity in current philosophy of biology. Second, I examine a specific critique that builds on the consensus view: Zach and Greslehner's objections to the "defense-strength metaphor" as a framework for scientific understanding of the immune system (2023). They identify an important aspect of immunological thought today, and show how the metaphor engenders misunderstanding. This paper builds directly on that work, shifting the focus to public understanding rather than scientific practices. My positive proposal also has implications for general philosophy of science – specifically, recent theories of understanding. Although these implications are compatible with most prominent philosophical theories of understanding, there are some tensions that warrant exploration in future work. So the case of non-expert understanding of immunity connects to several other scholarly debates and discussions. However, the primary goal of this paper is a contribution to socially-engaged philosophy of biology. It is, in a sense to be clarified shortly, *for* non-experts about immunology and its ideas. Deeper exploration of the theoretical implications for philosophy of immunology and general philosophy of science is a project for future work.[3]

This paper is organized as follows. Section 2 reviews the current consensus in philosophy of immunology and theoretical immunology, then examines Zach and Greslehner's critique of

conception, arguing for a more contextual, ecological view of immunity (see references in Section 2). These treatments are broadly compatible with the view proposed in the following sections, although directed to a different end.

[3] Fagan (2023, 2024, 2025) make a start on this project, although there is more to be done.

the "strength" metaphor in detail. Section 3 adapts these earlier ideas to the matter of public understanding of immunology, showing the problem in that arena. Section 4 uses results of the previous section to articulate desiderata for a solution, and then presents one that satisfies them. The latter is a three-part conceptual framework for non-expert understanding of immunity. According to this schema, immunity is yours, efficient, and specific (YES). Section 5 considers implications of this schema for public understanding of vaccines, and for philosophical theories of understanding, setting the stage for future work. Section 6 concludes.

2. Background: defense, strength, and the extended view of immunity

First, some terminology. An organism compositionally includes multiple bodily systems, of which the immune system is one.[4] Activity of the immune system is referred to as "immune response." In what follows, I will use the term "immunity" to refer to an organism's *general* capacity for immune response, and "immune response" to refer to some *particular* activity of an organism's immune system. So, for the purpose of this paper, "the immune system" refers to the bodily components and processes of an organism that interact to produce all its immune responses. Any particular immune response is *to something* (the technical term for this "something" is "antigen," but I shall leave technicalities aside in this paper, insofar as possible). An organism's immune system produces myriad immune responses; its capacity for doing so is "immunity."

The traditional conceptual framework for theorizing about the immune system is that it is *for defense*; i.e., the immune system functions solely or primarily to defend organisms against

[4] Other bodily systems are circulatory, endocrine, neural, etc. Note that an organism's systems are not "closed" or isolated from one another, or from other bodily components (see below).

pathogenic attacks. This idea is frequently paired with a contrastive dichotomy: "the self/non-self distinction." That from which the organism is defended by the immune system is "non-self," such that the immune system's function is theorized as "defense of self vs. non-self." It is then but a short step to conceptualizing the organism's boundary with the environment – the demarcation of self from non-self – to be part and parcel of the immune system's defensive function. That is, the organism is constituted as *an individual self* by the immune system's defense responses to non-self "invaders," internal or external. On this view, the immune system functions primarily to defend the self (a biological individual or organism) from attacks by non-self (externally-derived pathogens such as viruses, bacteria, and parasites). Cases of "immune response to self" (e.g., tolerance, auto-immunity) are thus pathological or in some other way exceptions to normal immune function. Boundaries of "the organismal self" are maintained by defense from non-self. In this way, the immune system delineates the organism as a biological individual; immunity *individuates* each organism as a unique "self." Defense is demarcation is organismal individuality, identity, selfhood. Organismal individuation is accomplished by *defense from attack* - giving a stridently martial, aggressive cast to this way of understanding immunity.

The idea of "defense of self from non-self" has long been a cornerstone of immunology as a science, arguably from the field's inception.[5] It has been enormously productive and fruitful, and remains deeply entrenched in immunological thought. But it also raises social concerns, as many commentators have noted. Metaphors of war, aggression, and strength abound in discussions of immunity premised on the "defense of self" conception. These associations, as

[5] See, e.g., Burnet and Fenner (1949), Klein (1982), Paul (1983), Silverstein (1989), Tauber and Chernyak (1991), Janeway (1992), Löwy (1992), Tauber (1994), Pradeu (2012).

well as themes of individualism, purity, and territoriality/invasion, have been examined and critiqued in the social, political, and anthropological literature on immunology.[6] That literature is continuous with important projects in philosophy of immunology, which criticize and update the defense view with more inclusive, interactive, and less "self-oriented" conceptual frameworks.[7] In philosophy of biology, critiques of the "defense of self" view tend to merge more with theoretical immunology (i.e. philosophy of science in practice) than with broader socio-cultural critique. For the purpose of this paper, philosophy of biology in this narrower sense is an appropriate starting-point. A fuller consideration of social perspectives on immunity and the immune system is a task for future work.

Philosophy of immunology in this narrower sense, continuous with theoretical immunology and pursued by or in collaboration with practicing immumologists, tends to criticize the "defense" view of immunity on empirical grounds.[8] Decades of immunology research have revealed multiple functions of the immune system, beyond just "defense." These include: maintaining homeostasis, contributing to normal development, synergizing with endocrine function, tissue repair, nervous system function, and clearing cellular debris. Moreover, we have learned that the immune system is intricately integrated with other bodily systems - endocrine, neural, vascular; perhaps more. It is not uncommon in science for a successful conceptual framework (or model, or theory) to produce knowledge revealing that framework's own limits, motivating a successor view. That seems to be the situation for the "defense view" of immunity

[6] See, e.g., Martin (1994), Cohen (2009), Brown (2019), and Neocleous (2022). A project for future work would be to assess how these scholarly proposals could combine with the framework proposed here (Fagan and Schneider, in preparation). Thanks to an anonymous reviewer for raising this issue.
[7] See, e.g., Weasel (2001), Tauber (2017), and Schneider (2021).
[8] See e.g., Janeway (1992), Matzinger (1994, 2002), Pradeu (2012); reviewed in Pradeu (2019) and Swiatczak and Tauber (2020).

today: a formerly productive and fruitful conceptual framework that has reached its limits and is now outdated. This motivates what Pradeu (2019) terms "extended immunity": the view that defense is one of several overlapping functions of the immune system, alongside organismal development, wound repair and regeneration, clearance of debris, and maintaining homeostasis. A further extension is immunity's entanglement with other bodily systems, in ways not fully understood. Scientifically then, the problem with defining immunity in terms of defense is that this is incomplete, effacing other functions and systemic relations of the immune system for which we have good evidence from decades of immunology research. This empirical argument motivates the extended view of immunity, as well as more explicitly ecological, systems-theoretic, and interactive conceptions of the immune system.[9]

Relatedly, there is no scientific or philosophical consensus today on the definition of "immunity" or "the immune system." Instead, various proposals are on offer, with some shared themes. For example, Tauber (2017) advocates an "ecological view" of the immune self not as a fixed entity but dynamic, emerging continuously from interactions between the organism as traditionally conceived and its internal and external environments. Similarly, Eberl (2016) proposes that "the healthy immune system is always active and in a state of dynamic equilibrium between antagonistic types of response…regulated both by the internal milieu and by the microbial environment" (524). Pradeu (2012) offers the "continuity theory" of what triggers an immune response, that being any unusual molecular patterns ("strong discontinuity") in the antigens with which components of the immune system interact (136-137). Immunity is thus a downstream consequence of the immune system's "recognition" of discontinuity. An early

[9] See note 7. Whether the "defense of self" framing was always false, misleading, or wrongheaded is a different issue and argument; see note 6.

theoretical alternative, Matzinger's "danger model" (1994) conceptualizes immunity as a response to anything recognized as dangerous to the organism.[10]

These and other "beyond defense" alternatives to the traditional view are prominent in philosophy of immunology today, although their impact on the science is more equivocal. The latter issue is the starting-point for Zach and Greslehner's (2023) critique of the "defense-strength metaphor" in immunology. It is the "strength" aspect, specifically, that my account builds upon.[11] The defense view, Zach and Greslehner claim, "naturally invites the talk of *strong* immunity and *strong* immune response," and correspondingly, of weak immunity and weak immune response (38:7-1; italics in original). Strong responses are (in some sense) more effective and thus beneficial to the organism. It is then a very short step to assuming that an organism's immune system or general capacity for immune response is characteristically strong or weak. Zach and Greslehner observe that immunologists often describe an organism's immune system, or a particular immune response by that system, as "strong" or "weak." Such characterizations have an evaluative aspect: a "strong defense" is desirable and beneficial for an organism's health, a "weak defense" the opposite. There are, Zach and Greslehner claim, two problems with conceptualizing immunity in this way. First, the descriptors "strong" and "weak" are ambiguous, with multiple meanings inviting misinterpretation. Second, even if disambiguated, the "strong vs. weak" conception implies a single continuum or axis on which immune responses can be measured and evaluated. But that is empirically inaccurate. An organism's immune system has many dimensions or aspects of function, which don't fall on any

[10] Land's "injury theory" is a variant of Matzinger's, independently conceived (Land and Messmer 1996).

[11] Zach and Greslehner also discuss the roles of metaphors in biology; this aspect of their paper raises interesting resonances and tensions with Reynolds (2017) on metaphors in cell theory and cell biology. Exploring these is a project for future work.

single axis relevant for understanding immunity. So the "strong vs. weak" framing is misleading as well as ambiguous. Conceptualizing immune responses as "strong or weak" oversimplifies the multidimensional complexity of those responses and so hampers understanding.

The idea that an organism's defensive immune responses can be cogently evaluated as "strong" or "weak," is the target of Zach and Greslehner's distinctive critique of the traditional view of immunity.[12] On the positive side, they offer their own successor framework, which better conforms to current immunological knowledge. Their proposal consists of three themes: contextuality, regulation, and tradeoffs. "Contextuality" refers to the fact that "the outcome of an immune response is essentially dependent on the context which in turn is determined by a multitude of factors" (38:7-11). The same molecular or cellular component can play different roles in an immune response, depending on the situation. "Regulation" refers to the complex "array of feedback mechanisms… finely tuned and tightly regulated," spanning multiple levels of organization, involved in the immune system (ibid). "Tradeoffs" refers to the diverse roles that one feature of an immune response can play; e.g., benefitting the organism under one set of conditions, and harming that organism under another set of conditions. There are desirable things for an organism that can't all be had at once – clearing an infection vs. avoiding tissue damage; specific genotypes that benefit or harm an organism depending on the context.

One might push back on Zach and Greslehner's argument by appealing to *scientific expertise*. For experts (i.e., immunologists) it may be that the "strong vs. weak" framing does not lead to serious misunderstanding, confusion, or mistaken inferences. One of the requirements for being an expert in immunology is understanding the limitations of this oversimplified framing.

[12] The idea of immunity as a "defense system" with responses that can be evaluated as "strong or weak" is, they claim, the "dominant characterization of the immune system found in immunological literature" (38:7-2).

(Indeed, one might take such understanding to partly constitute expertise in immunology.) Characterizing immune responses as "strong vs. weak" is convenient, easy, and very incomplete - misleading in some circumstances. But those nuances are precisely what immunologists know about, and so their expert understanding can compensate for the framework's limitations.[13] Relatedly, it's important to recognize that expert understanding of the immune system is imperfect and incomplete – and such recognition is itself an aspect of expertise in this area. Research on the immune system is, necessarily, done from an epistemically-limited position; we do not have, and never have had, complete knowledge of the immune system of any organism whatsoever. Awareness of the limits of immunological knowledge central to expertise in this field.[14]

3. Immunity in everyday contexts

Within immunology, expertise arguably renders the "strength" metaphor harmless.[15] However, outside immunology, there's little or no mitigating expertise. This section argues that the defense-strength metaphor is, if anything, *more* prevalent and problematic in everyday contexts than in science. Insofar as it bears on vaccine decision-making, this flawed conception has significant social impact. While Zach and Greslehner (2023) are not unaware of public understanding of immunology, their critique and positive proposal are focused squarely on the

[13] Use of "strong vs. weak" framing could also be analyzed as a case of scientists productively using idealizations in their knowledge-producing research (Potochnik 2017, Rice 2021). Another related debate is the relation of philosophical theorizing to scientific practice (see, e.g., Kovaka 2015, Clarke 2025).

[14] I argue that this is a significant feature of immunology's social epistemology in (Fagan 2023, 2025).

[15] I think Zach and Greslehner can respond to this rebuttal, although I do not pursue that line of argument here. Note that criticisms of the defense metaphor discussed previously remain in force, even if one grants the objection raised here.

science of immunology. They argue that scientists should abandon the simple metaphorical framework of "defense" and "strength," and instead pursue a general theory of immunity building on the three themes of contextuality, regulation, and tradeoffs. Those themes are a high-level summary of our current best scientific understanding of the immune system and its workings. They are not metaphorical, idealized, or intended to play a background role. Rather, Zach and Greslehner's new conceptual framework is intended as a stepping-stone toward a new theoretical approach in immunology. It is aimed at scientists working in immunology and related areas, not the general public. Although several passages mention wider audiences and impacts in (38:7-4, 38:7-5), Zach and Greslehner's paper does not address the defense-strength metaphor as an aspect of non-expert understanding. That is the task of this section.

Although immunity and the immune system are not omnipresent topics in everyday discussion and reasoning, they do come up in relation to lifestyle, health, wellness, and childcare.[16] I'll discuss the last shortly. In matters of lifestyle, health, and wellness, the "strong vs. weak" conception of immunity is so prevalent as to be nearly universal. It is rare to encounter any discussion of immunity in these contexts that doesn't presuppose some version of this framing. If anything, characterizing an immune system or response as "strong" or "weak" is *more widespread* in everyday life than in science.[17] Two examples will illustrate.

Example 1: "Boost"

[16] During the recent COVID-19 pandemic, immunity and the immune system were, for obvious reasons, more on non-experts' minds than is usual. This will happen again.
[17] To my knowledge, there is no social science research on public understanding of immunity and the immune system specifically, outside of assessments related to vaccine attitudes. I discuss those attitudes, and their bearing on the "strength" conception, below.

Many nutritional products and health supplements tout among their benefits a "boost" to one's immune system. In my local grocery store, a popular product is the Vive Organic™ Immunity Boost Vitamin C Shot – the concept is right in the name.[18] (The "shot" is one you drink instead of getting via a jab in the arm – a mild joke at the expense of vaccines.) The term "immunity boost" isn't defined on the label, but the intended meaning can be inferred from commonsense meanings of the two terms. "Immunity" is the body's ability to maintain health in the face of exposure to pathogens ("immunity" from some attacker). "The immune system" refers to diverse components within the body that collectively have that ability. A "boost" improves one's immune system's ability, so as to better maintain or recover health in the face of some pathogen or disease.[19] The causal claim implied by "boost" is cogently analyzed in counterfactual terms; if one didn't drink this shot, one would be more likely to sicken, recover more slowly, or both. Positive customer reviews (many obtained in product promotion efforts) credit this drink with maintaining their overall health, fighting off infections, and speedier recovery from illness. This all seems pretty innocuous. An "immunity boost" gives one *better* immunity, to – something; some pathogen or collection of pathogens. But this simple causal claim has implications for how the immune system works. Most saliently, its working can be better or worse. This way of thinking about immunity presumes an evaluative axis, ranging from sickness to health. It is very easy to conceive this evaluative axis as coinciding with the "strong-weak" axis for evaluating an immune response. The "defense" framing is already implicit, as is the single evaluative dimension. A "boost" is, intuitively, an increase in something. Absent any concrete

[18] Ingredients: organic apple juice, organic ginger root juice, organic acerola cherry puree, organic turmeric root juice, organic acerola cherry extract, organic ground black pepper, Bacillus Coagulans Snz 1969.

[19] The distinction between pathogen and disease is of course fundamental in medicine, but in everyday contexts it is often elided.

characterization of immune system components and how they interact, it's reasonable to conceptualize the "boost" as simply strengthening one's immune system.[20] A network of associations ("boost-better-stronger-faster-healthier") accretes around the concepts of immunity and the immune system. This network amounts to an everyday, commonsense, non-expert conception of immunity and the immune system. What, if anything, is wrong with this conception? How (if at all) does it fall short of understanding?[21] One problem echoes the critique above: the immune system's working is too complex and multifaceted to be "boosted"; i.e., for its activity to be uniformly increased or decreased for a uniform effect on health. A second example reveals further problematic implications.

Example 2: "No immunity without challenge"

In the second autumn of the COVID-19 pandemic, a Salt Lake City newspaper featured an article about ongoing challenges to education. The headline and subtitle read "Front-line fatigue: Many teachers, staff face utter exhaustion in 'an untenable situation.'" (Rollins 2021). A few paragraphs into the article, an immunologically jarring statement appears:

> And those remaining are having to take more sick time than ever because either they or a family member has COVID-19 or some other kind of illness they picked

[20] The Harvard Health Letter (2025) makes this connection obvious via its title "How to boost your immune system" with the sub-title "Helpful ways to strengthen your immune system and fight off disease." The article itself states, very much in line with Zach and Greslehner (2023) and the argument of this paper, that "The idea of boosting your immunity is enticing, but the ability to do so has proved elusive for several reasons. The immune system is precisely that — a system, not a single entity. To function well, it requires balance and harmony. There is still much that researchers don't know about the intricacies and interconnectedness of the immune response. For now, there are no scientifically proven direct links between lifestyle and enhanced immune function."

[21] Philosophers of science may be inclined to say the answer is obvious: this network of associations differs from our best scientific knowledge (or understanding) of the immune system. See Section 5.

> up at school because *immune systems have taken a hit from people mostly staying at home* — and even a mild cold could become severe with *no immune system to tackle it.* (italics mine)

The italicized passages indicate very serious misunderstandings about immunity and the immune system. I am not singling out this particular article or its author for criticism – quite the opposite. The ideas stated here are very common and widespread in US society today (and likely in at least some international contexts as well). The quoted passage is part of a well-intentioned series of articles about "front-line fatigue" in healthcare workers and other workers in Utah; immunology is not the point of the article at all. But the quoted passage does vividly and concisely illustrate several common, related misunderstandings about immunity and the immune system. I'll discuss the two problematic, italicized claims in turn. The first is a causal claim: staying at home instead of working (as a teacher) outside the home leads, somehow, to having a "weaker" immune system. (I can't see another way to interpret the phrase "taken a hit" here, than as some form of injury or "weakening.") This is a double misunderstanding. First, conceptualizing and evaluating the immune system on a single axis of performance is oversimplified and inaccurate (see Section 2). Second, the causal claim lacks evidential and theoretical support. There is no connection, even correlational (to my knowledge), between one's work location and immune system function. Furthermore, our current immunological knowledge doesn't offer any reason to think there would be such a causal connection (this is what I mean by "lacking theoretical support"). So from a scientific viewpoint, this claim is doubly mistaken.

The second problematic claim, while literally correct from a scientific point of view, is even more misguided. "A mild cold could become severe if a person has no immune system." There are at least three misunderstandings involved in this claim. First, a person without any immune system whatsoever could not survive (see Section 4). The situation of catching a cold of

any degree of severity would not arise; it is physiologically impossible. Second, and relatedly, the phrasing in terms of possibility, risk, and the progression from "mild" to "severe" is misleading. For an organism lacking any sort of immune system (if we decide to entertain the possibility of its existence), any infection is a death sentence. Thirdly, in the article, the claim is not logically related to previous claims. It shoots right to the bottom of the slippery slope from a weakened immune system to its total absence. The "strong vs. weak" framing is central to all these misunderstandings (slippery slope fallacy excepted). Here I am going to speculate a bit. In the absence of any scientific understanding of the immune system's components and processes, many people default to the idea that it works similarly to muscle. The "strong vs. weak" framing encourages this idea, muscle being the body tissue most associated with strength. Most non-experts don't understand the molecular and cellular details of muscle physiology and development either, but many are familiar with the idea of building muscle to increase strength. And on the other side, most people are aware that muscles atrophy if not used; one's muscles get weaker if not exercised somehow. "Strength vs. weakness" for immunity doesn't manifest in the way of muscle strength or weakness, of course. Here the "defense" framing comes into play. A strong immune system successfully defends a body against attack from diseases. That strength is built through exercise, and lost without such exercise. Exercise, for the immune system, is the work of conquering pathogens – the system's defining function. So, not exposing people to pathogens weakens their immune systems; one's immune system atrophies if not regularly exercised in defense.[22] In this way, the "defense-strength" metaphor, augmented by an analogy with muscle, encourages ideas like those in the quoted passage. One's immune system becomes strong by being built up through challenges. The training practices that make for strength in

[22] This is classic analogical reasoning (Hesse 1966).

muscles are analogized to the immune systems' successful conquest of pathogens. Given this framing, it makes sense to think of immune systems as atrophying in the absence of challenges, and sitting at home being one means to such atrophy. Something like this is, I think, the mindset at work in the quoted passage, and in many discussions of immune and immune systems focused on health, wellness, or lifestyle.

The conceptual framing of immunity as "strong vs. weak" is the lynchpin of all these associations. All are serious misunderstandings of immunity and the immune system, as noted above.[23] The defense-strength metaphor is if anything *more* distorted and misleading in everyday contexts than in professional scientific or medical settings. Social harms of these misunderstandings are clearest in matters of vaccines and health policy. It is beyond the scope of this paper to survey these controversies fully. In the US (and beyond) our society now faces serious problems about vaccines and vaccine policy. Social phenomena of vaccine skepticism and hesitancy are multifaceted, with epistemic, medical, political, and ethical aspects.[24] Anti-vaccine efforts are the thin end of the wedge of anti-science propaganda and associated epistemic crises in the culture at large. Conceptual change is only one aspect of addressing these crises. The non-expert conception of immunity proposed here is no panacea. Yet replacing the defense-strength metaphor with a less misleading network of associations could be helpful for such

[23] Importantly, though, they are reasonable ideas for non-experts to arrive at, in the absence of knowledge or understanding about the immune system. For reasons to be discussed shortly, that knowledge/understanding tends to remain the sole province of experts. Section 4 offers a solution to this problem.

[24] There are other reasons for vaccine hesitancy than commitment to misunderstanding the science (Goldenberg 2016). Members of communities who have been historically underserved or harmed by biomedicine may be justifiedly reluctant to trust its offerings now. Perhaps understanding the immune system could help alleviate that situation, although this cannot be the whole solution.

efforts. There is no understanding of how vaccines work without understanding of the immune system.[25] To direct that positive proposal, I want to highlight one more aspect of everyday attitudes toward vaccines, that implicates concepts of immunity and immune systems: *autonomy*.

Autonomy, philosophically speaking, falls into the domains of bioethics and political philosophy – both largely separate from philosophy of science. Bringing these literatures into closer contact is worthwhile, although I'll not attempt that here. My treatment of autonomy is in the commonsense vein, appropriate for this paper. Vaccines are, in everyday contexts, conceived as *doing something* to one's immune system. In the absence of scientific understanding of the immune system's components or workings, ideas about what a vaccine does are likely to be vague and fuzzy.[26] But there is a clear causal view: a jab in the arm conveys something into one's body, and that something *does something* to one's immune system; one's immune system is altered in some way. The intended (or alleged) effect is to "strengthen" one's immune response to a specific disease, but how this "strengthening" operates is obscure. What is clear, from this point of view, is that other social actors - medical and/or political authorities – are *doing something* to one's immune system; exercising some form of control over it. The goal of that control is beneficial (health) – but even if one doesn't doubt this, there is a loss of bodily autonomy, of control over a system in one's body, involved in getting a vaccine. To get a vaccine is to cede control over one's immune system to some external authority, medical or political. A

[25] Arguably the reverse is also true; origins of immunology as a science are tied to theories and methods of vaccination, and to the goal of immunity to life-threatening diseases (see, e.g.. Silverstein 1989, Moulin 1989). Although this recommendation and framing of the problem differs from Goldenberg's (2016) reframing in terms of distrust of experts, my proposal could be interpreted as contributing to the mutual dialogue she recommends, replacing one-way knowledge transmission as a fix for public ignorance. The problem I diagnose is not ignorance of science, but rather the lack of an accessible non-expert conception of immunity.

[26] For those inclined, there are many excellent introductory resources for learning about vaccines (e.g., Welsh and Updyke 2019).

vaccine may make one's immune system stronger, but by the same token (or jab) it makes that system less one's own.

Ideas of autonomy and control are even more complicated and fraught when we consider vaccines for children. Decision-making about children's healthcare (in the US and many other national contexts) is exceedingly gendered. The caregivers who think and reason about immunity in this sphere are predominantly women. For many women, features of their cultural background dictate that matters of childcare are one of few areas in which they are socially expected to make decisions in a way that might be characterized as autonomous. Ceding control over this area, decisions about one's children's health, is a breach of autonomy tied to a morass of tensions and violations, that can deeply impact one's sense of self and one's place in social life. For all these reasons, the stakes concerning autonomy in vaccine decision-making are very high. In thinking and reasoning about vaccines, a sense of defensiveness about bodily autonomy, and about the right to make decisions concerning one's children, are often in play. Added to these are multiple misunderstandings encouraged by the "strong vs. weak" conception of immunity. Again, remedying those misunderstandings cannot resolve all the tensions and problems associated with vaccines and immunity. But it would help, to have a less misleading conception that can speak to the issue of autonomy. Even a small contribution toward solving problems around vaccine policy and anti-science attitudes is worthwhile. The next section offers such a contribution.

A deflating objection might be raised here. Don't we already have accessible introductions to the immune system? This section aims to motivate a new conceptual framework for understanding the immune system that is accessible to non-experts and doesn't foster misunderstanding and thereby exacerbate broader social problems. But there are already many, many introductory overviews of the basics of immunology, aimed at non-expert audiences. So

isn't my project redundant? I shall argue that it is not. In the process, some important features of non-expert understanding are brought out. These in turn help shape the positive proposal in Section 4. The key point is that existing introductory treatments of the immune system do not (and cannot) play the same epistemic role as the defense-strength metaphor. Such introductory treatments are designed to communicate scientific information; to transmit (some) expert understanding outside the sciences. The problem I diagnose is not ignorance of science, but rather the lack of an accessible non-expert conception of immunity. To see the difference, consider some examples.

There are many simple educational introductions to the immune system.[27] Thomas Pradeu's *Philosophy of Immunology* in the Cambridge Elements series (2019) is a good example. This work distills "defense against pathogens" – arguably the immune system's primary function – to a single, economical paragraph (3-4). However, that short summary is followed by a more comprehensive (yet still very simplified) overview of (i) nine major cell types of the mammalian immune system, (ii) twenty-one functions variously performed by these cell types, (iii) two major molecular components of the mammalian immune system with (iv) four of their functions, (v) a diagram of ten major organs of the human immune system, and in the same diagram, (vi) the network of lymphatic vessels that distributes cells and molecules of the immune system throughout the human body (4-5). Even the one-paragraph summary of one function (pathogen defense) includes many specialized technical terms: "macrophages," "inflammation," "innate," "antigen-presenting cells," "lymphocytes," "affinity," and more. Pradeu's introductory overview

[27] This is not to suggest that expert knowledge/understanding of the immune system is complete, perfect, or absolute. It is, as noted previously, none of those things (see Fagan 2023, 2025). Immunologists do have technical, expert knowledge of their area of study, and STEM education is oriented toward transmitting that knowledge, imperfect and partial as it is.

is aimed at a general educated audience, and is very concise and accessible. Yet it's still fairly complex. There are a lot of specific moving parts, interactions and activities, compartments and components – all unfamiliar to most readers; i.e., anyone not already familiar with the basics of immunology.

Introductions to immunology in other media, outside academia, are similarly complicated. The TED-Ed animation "How does your immune system work?" is a 5.5-minute video that overviews major immune system components, designed for general audiences.[28] The animation uses a military metaphor overall (battle of "you" vs. "threats") but also the metaphor of "cell conversation." Cells are depicted as the main active components driving an immune response, working in organs and tissues in response to an event (a mosquito bite) in a stylized representation of emergency services. Ideas of surveillance, screening, and security vs. foreign invaders are highlighted. The animation is skillfully made and conveys some important features of immune response – but it relies very heavily on the "defense" metaphor, thus leaning into all the problems discussed previously. Immunity is represented as a cell-mediated defense against external threats. Many details are omitted, such that it appears as though molecular "lock and key" matching between immune components and an invading pathogen is the trigger for destroying that pathogen – glossing over many intermediate interactive processes. The connection between "recognition" and "defense" is assumed, not explained.

[28] Bryce et al (2018). See also, Sana Khan's educational animation offers "compelling dynamic visualization for optimal understanding of the complex and critical biological processes underlying long-term immunological protection" (2021), and educational software "Virtual Immunology. The Antigen-antibody interactions" (Faggioni et al 2022). The latter study didn't find a statistically significant difference in learning performance attributable to use of this software package, although an effect was detected.

Another everyday metaphor appears in the TED-Ed video: a *conversation*. This metaphor is further developed to introduce some major immune system components and their interactions in "This podcast will kill you" episode 26 (Welsh and Updyke 2019). The hosts provide a very accessible, simplified overview of the immune system. They begin by distinguishing the innate and adaptive branches: the former quicker-acting but less powerful, the latter slower-to-act but highly effective against specific pathogens. (It's a very good, accurate, basic summary.) The hosts then use the metaphor of a play, with Acts corresponding to stages of an immune response, and a host of characters appearing in diverse combinations across four Acts. They distinguish three major roles, all for different kinds of white blood cells. They then work through the script of the play, translating key molecular/cellular interactions of an immune response into familiar conversational patterns. All these are everyday, accessible concepts – but it is still a lot of memorization of a many details. The play itself is a lengthy section of the episode. While each key component and interaction is represented in an accessible way, as with other introductory treatments, the "script" as a whole is quite complex. The idea behind these accessible introductions is sound: translate the biological concepts into terms familiar to non-experts. But this is done at the grain of specific components and activities. The metaphorical story takes awhile to tell, although the hosts/authors/visual designers do a very economical job of compressing the information.

All these are worthwhile efforts at immunology education for the general public. But they are not simple metaphorical schemas that could replace the "strength" metaphor likening the immune system to muscle. The initial metaphor – a business, military effort, or bar conversation – is filled in with many details, representing the immune system's interactive complexity. These are simplified versions of scientific introductions to immunology, indicating the main players

and interactions. The initial metaphor, on its own or as a simple slogan, doesn't suggest much about the immune system or how it works. Filling in the details is what makes for a representation of the immune system; all the introductory treatments I'm aware of work this way. I'm not claiming that it's impossible or even very difficult to learn these basics. What I am claiming is that it is very difficult to achieve even an introductory understanding of the immune system *if one is not already committed to learning about it* – without studying immunology, or taking an active interest in its ideas as a layperson. Most people on the planet are not so committed, and have other interests than learning immunology.[29] And they are no worse off as epistemic agents for this. For these people – most people - even a concise, simplified, and relatively jargon-free introduction to the basics of immunology is likely to make their eyes glaze over. Not so the "strong vs. weak" framing. That idea is intuitively accessible and makes sense to a very wide audience. Problems ensue because this accessible interpretation is inaccurate and misleading. What's wanted is a framework for understanding that immune system that is just as accessible to non-experts, but which represents the immune system according to our best current science while addressing concerns about autonomy noted above.

Circling back to the start of this section, Zach and Greslehner's three themes (contextuality, regulation, tradeoffs) are simpler than the educational introductions reviewed above. Their proposed framework accurately captures key features of the immune system without including daunting masses of detail; just three thematic components. However, these particular three themes aren't well-suited to a broad non-expert audience. There's a pronounced

[29] There are also significant educational barriers, which in many countries (including the United States) put life science concepts epistemically out of reach for many groups of people.

technical flavor to the ideas of "contextuality," "regulation," and "tradeoffs." That is reasonable, given the 2023 paper's purpose. My purpose is different, so a different tack is required.

4. Immunity for non-experts: the YES schema

Reviewing the problems and challenges for non-expert understanding of immunity provides guidelines toward a solution. For one, the standard "deficit model" for public understanding of science is not appropriate here.[30] That model is just what it sounds like: efforts to improve understanding of scientific concepts and theories are conceptualized as addressing an epistemic deficit in members of the public. The deficit is remedied by transmitting scientific knowledge into everyday, non-expert contexts. But, as educational introductions to the immune system show, direct transmission of expert knowledge is not a practical solution. Our best current scientific knowledge of the immune system is exceedingly complex, not readily summarized, and rife with highly technical concepts. Persons not antecedently motivated to learn about the immune system are not likely to engage with these treatments, however valuable they may be for persons who are so motivated. And lacking that motivation is not an epistemic failure. More generally, being a non-expert is not an epistemic deficit; it's just the situation we are all in, with respect to knowledge today. What is needed, to address the problems presented above, is a conceptual framework that meets non-experts where they are. More specifically, it needs to meet four requirements. The new framework should be:

- simple, in the sense of requiring little memorization; composed of few 'moving parts';
- accessible; i.e., presuming no specialized knowledge of immunology or even biology;

[30] In this respect, I follow Goldenberg (2016). For more discussion of the deficit model and its limitations, see that work and references therein.

• address concerns about autonomy and control, as discussed above; and

• mutual, in the sense of forming a 'bridge' between our best current scientific understanding of the immune system (expert knowledge) and everyday experience.

Satisfying all four requirements is a challenge. The solution is not to "just add scientific understanding". What works for STEM experts - and students aiming to become so - is not suitable for a wider non-expert audience. It's unreasonable and impractical to expect those who aren't already motivated to study immunology to take the time to grasp all the relevant details. Even introductory treatments are too detailed and complicated to convey understanding for a non-expert audience. Instead, non-expert understanding should be approached on its own terms. The new framework needs to acknowledge the immune system's complexity without delving into its details, capturing its working using everyday concepts. The "mutuality" requirement replaces the traditional one-way interaction associated with the deficit model. In other work, I've proposed norms and guidelines for constructing mutual, collaborative 'bridging' connections between scientific models (Fagan 2017, 2020, 2025). The mutuality requirement here extends that account to non-expert contexts. Very briefly, instead of one-way interaction, a conceptual framework for non-expert understanding amounts to a form of interdisciplinary connection: a mutual, collaborative activity, which can be evaluated by norms for such activities. A mutual connection that captures key scientific insights about the immune system as a complex system in a way that is accessible and easy to grasp without any prior technical background is a tall order. The immune system often works counterintuitively, while easy-to-grasp metaphors, as we've seen, are often misleading.

To meet these challenges, I propose a schema with three conceptual components; three main ideas. They are not technical, and do not presume either interest in or background

knowledge of biological sciences. These ideas are informed by, and reflect, our best current expert understanding of the immune system and its workings. But the goal is not to *transmit* that expert understanding *to* non-experts. Instead, the three-part schema *connects* our best current scientific and philosophical understanding of the immune system *with* commonsense, everyday experience. The latter is central for non-expert understanding. Lack of connection between scientific concepts concerning immunity, and everyday life outside immunology, is the core of the problem. Having no obvious way to connect the immune system's components and processes to one's own life and concerns makes those scientific concepts less accessible to non-experts. The following schema aims to fill that gap, articulating three central features of an immune system. It is:

(i) yours

(ii) effective

(iii) specific

The acronym YES is appropriate. Each of (i)-(iii) is grounded in scientific evidence and philosophical theorizing, while also engaging everyday experience. The rest of this section clarifies the meaning and grounds of each component, showing its suitability for non-experts through satisfaction of the four requirements noted above.

(i) *Yours: organisms and the immune system*

Your immune system is *yours*, inalienably – it cannot be otherwise, while one is a living biological organism. No other person, no group of people, no force in the world, can separate an organism from its immune system while that organism is alive. This is a commonsense idea, and simple in the required manner. Most if not all people are familiar with the idea of being a living organism; of having a body that experiences phenomena of health and disease. Immunity is

inextricably connected to one's own body, to one's everyday life in all its activities. One needn't have any STEM background to engage with this notion. Yet insights from immunology and philosophy of immunology underpin (i), notably the extended view of immunity (see Section 2).

One aspect of this extension is phylogenetic. Most if not all living things have some form of an immune system: vertebrates, invertebrates, plants, bacteria, archaea, etc. (Rimer et al 2014). Earlier conceptions of the immune system were more phylogenetically limited, referring to white blood cell-mediated branches and associated processes of genetic rearrangement specific to vertebrates (today referred to as "adaptive immunity"). However, it has long been known that there are other immune processes with wider phylogenetic range, referred to as "innate immunity." Recent decades of immunology research have revealed many close ties between "adaptive" and the more evolutionarily ancient "innate" immunity, as well as mechanisms in bacteria, archaea, and plants that fulfill many of the same functions.[31] So the view that immunity is a feature of all or most biological organisms is increasingly prevalent, both in immunology and philosophy of immunology. New knowledge of the components and processes of innate immunity as well as of the myriad interconnections between the functioning of the two branches, makes for richer and more detailed models of the vertebrate immune system as well. So the phylogenetic extension of immune ideas is (at least arguably) coupled with better scientific explanations of vertebrate immunity.[32]

Progress in understanding functions of the immune system shows the same pattern. Immune responses associated with defense are increasingly well-understood in a wider range of

[31] See, e.g., Rimer et al (2014), Schneider (2021), Pradeu et al (2024).
[32] The received view within expert communities in many life sciences is that the more complete a description of interactions among cells, molecules, tissues, and organs over the course of immune response, the better the explanation – i.e., the more understanding conveyed (however, see Section 5).

organisms, alongside new knowledge about its other functions within an organism. These other functions include homeostasis, development, tissue repair, and perhaps even effects on behavior and cognition (see Section 2). Alongside extended functions, the immune system is intricately connected to other bodily systems: endocrine, nervous, circulatory, and perhaps more. Although the specifics of these inter-system connections are not fully understood, these are topics of ongoing inquiry. Several sub-areas of current immunology are dedicated to understanding these connections in their full molecular, cellular, and tissue/organ complexity.[33] All these conceptual shifts and expansions of the idea of immunity and the immune system serve to associate that system more closely with the life of an organism. Philosophers of immunology have noted this, offering theories of biological individuality and individuation of organisms from their environments (see, e.g., Pradeu 2019, 23-24, 26). The various activities of one's immune system throughout life are largely responsible for maintaining an organism's integrity as a living being. One important role of immunity is the dynamic, continuously re-delineated distinction between a biological individual and its environment (the latter consisting of other biological individuals as well as various abiotic factors).

These philosophical and scientific insights support a close conceptual association between the immune system and the life of an individual organism. Those insights collectively underpin (i): your immune system is not all that you are, but it is yours, and cannot be otherwise. It will work in you, maintaining your life, as long as that life lasts. Accessible to non-experts, (i) is grounded on our best current immunological thought; it isn't over-simplified or misleading in regard to the science. But (i)'s accessibility, connecting to commonsense ideas and everyday

[33] E.g., ecoimmunology, neuroimmunology, psychoneuroimmunology, reviewed in Swiatczak and Tauber (2020).

contexts, is just as important. Most people don't think of themselves primarily as biological organisms, but that we have bodies is a fairly unavoidable insight. So the idea that one has a life as a biological organism is pretty familiar, although of course there's more to any person than that. The key idea of (i) is that one's immune system originates with and develops alongside one's life as a biological organism. The two cannot be prised apart. Our lives as such are in part made possible by our immune systems – and, so each of us is the milieu of all immune interactions; the scene of immune response for the organism that is ourselves.[34] The working of the immune system supports our lives as persons. This idea connects the immune system directly and immediately to one's own body and experience of the world. In this way, (i) directly addresses concerns about autonomy. There is no way for another organism, or group of organisms, to "take over" your immune system; to control it so it becomes less than wholly yours. So this part of the schema satisfies the four requirements listed at the start of this section.

(ii) *Effective: sub-personal problem-solving*

The second idea in the non-expert schema that your immune system is *effective*. Being effective is a causal concept with evaluative connotations; to be effective is to do something well. That "something," for the immune system is, I propose, "solving problems for the organism." One's immune system solves problems that arise for one, as a biological organism. These are not personal problems, but sub-personal. So part (ii) of the YES schema means that one's immune system is effective at solving problems that arise for you as a biological organism. The idea of

[34] In Bernard's physiological theory (1879), a stable interior milieu is the sine qua non of "the more highly organized animals" whose lives are "characterized by freedom and independence" (ibid). That freedom and independence is enabled precisely by the interior milieu. The interior milieu makes possible a free and independent way of life, robust to the vicissitudes of external physical factors. This concept is apropos for understanding the immune system, although not in a general non-expert way.

problem-solving captures the breadth of activities of the immune system – exactly the extended functions and interconnections with other organismal systems that undercut the earlier "defense" conception (see Section 2 and previous). The idea of problem-solving is accessible to non-experts; everyone has problems. The problems your immune system solves are ones that arise for you as a biological organism. An organism's life has a beginning, middle, and end. Solving problems for an organism puts off the end, extending the middle. Thus, your immune system is inextricable from your life as a biological organism in at least two ways. First, as (i) asserts, it's inalienably yours; your existence as a biological individual is delineated, continuously and dynamically, by various activities of the immune system, including but not limited to defense. Second, as (ii) asserts, your life as a biological organism depends on the immune system's effectiveness in solving problems. Parts (i) and (ii) of the schema are two sides of the same coin.

As with (i), the idea that your immune system is effective is grounded on our best current scientific and philosophical understanding of immunity. "Effective" is more generic and inclusive than the idea that the immune system is for "defense of self," although defense functions are certainly included. Replacing "defense" with "problem-solving"as the immune system's main function eliminates the misleading "strong vs. weak" conception, as well as associations with more familiar everyday notions of strength, including the analogy with muscle (and building it up vs. losing it). This schema also doesn't support martial or police imagery, or metaphors of foreign invasion. Instead of metaphors of war, expelling dangerous foreign invaders, and muscular strength, the core idea of (ii) is extending one's life as a biological organism – maintaining health, but conceptualized in a very simple, inclusive way. One's immune system is for maintaining a long healthy life. Importantly, "effective" doesn't mean "perfect;" one's immune system doesn't successfully solve every problem that arises for an

organism. That's an unattainable ideal. But in light of the myriad problems that can arise, if you are a living organism, then your immune system is pretty effective overall. Though imperfect, one's immune system is constantly at work.

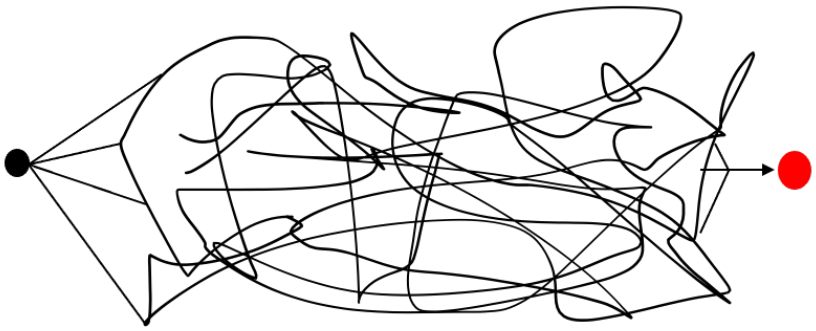
An objection that might be raised here is that "problem-solving" is too inclusive a characterization of the immune system's role in an organism. This framing suggests that every (sub-personal) problem for a biological organism is addressed by an immune response. Surely that is too broad? I am not so sure. Insights about the extended immune system show at least some, perhaps very extensive, entanglement with other bodily systems. Furthermore, the diverse functions attributed to the extended immune system do suggest that nearly any potentially life-ending problem will elicit some activity by some components of the immune system. Infectious diseases are of course one kind of problem, but so are challenges to homeostasis, normal development, endocrine and nervous responses… Because of the immune system's multiple functions, and its ties to other bodily systems, a generic, inclusive sketch of its role seems appropriate. Even if this is strictly speaking too broad, it seems preferable to err on the side of inclusiveness than the opposite. To sum up, "effectiveness" is interpreted as (mostly) successful problem-solving at sub-personal levels, so as to prolong the life of an organism. Your immune system is effective in exactly this sense – that's part (ii) of the YES schema. The idea, as with (i), is simple, accessible, addresses concerns about autonomy, and connects with expert insights while centering everyday experience.

(iii) *Specific: bounded complexity with a point*

The third and final part of the YES schema is immune *specificity*: your immune system's effectiveness in solving any particular problem is *specific*. As with effectiveness, the meaning of specificity in part (iii) is an everyday, commonsense notion, although grounded in our best

current immunology.[35] Harking back to (ii), a successful immune response is an effective response to some problem for the organism, aimed at helping that organism live a long healthy life. Each effective response toward that end has, so to speak, a finely-honed point. That's the meaning of "specificity" here; the narrow, precise end-point resolving a particular problem for the organism. This notion of specificity is most accessible as an image (Figure 1). The image of depicts immunity with a beginning (coinciding with the organism's beginning), a middle (characterized by complex interactions, shown as a scribbly tangle), and an end (the specific immune response to a particular problem). This 'bounds' the immune system's complexity, locating it between an organism's point of origin and the specific end-point of any effective immune response. The middle is a dense interconnected mass, constantly active, multi-level, multi-scale, multiply-connected with other bodily systems – all the complexity of a living thing with many active, integrated parts.

FIGURE 1



beginning:
organism &
immune system

middle:
complexity
ongoing life-sustaining activities

specific response:
deferring organism's **end**

[35] Philosophical theories of specificity in molecular biology or other life science fields can connect with the accessible, commonplace meaning here. But, for reasons that should now be obvious, the YES schema does not presume any technical philosophical concepts.

While not as simple an idea as (i) and (ii), (iii) is accessible, connected to everyday experience. The "beginning" of an organism's life and immune system is a simple idea, without any technical flourishes. Although there are many important scientific ideas about genetic, phylogenetic, or developmental identity associated with this starting-point, none of these are required to grasp the basic image (or structure) of immunity in non-expert contexts. From a non-expert perspective, the elaboration of immunity from this starting-point can be interpreted in various ways. For example, to borrow an image from Waddington (1939), the developing immune system divides into pathways, like many streams descending from a source. Cell and molecular components of the system form streams and pools around the body, carried in blood, eddying in lymphoid organs, contributing to the barrier of the skin. Different pathways of cell development lead to many diverse cell types, which circulate or gather at various locations in the body. Details of these branching pathways, features of resulting cell types, their various bio-active products, and diverse functions, could be investigated if one chooses, but need not be, to grasp the basic "shape" of the immune system; its continuous activity and complexity. When directed toward a specific problem for the organism, this circulating diversity converges with targeted precision, like a trap springing shut. A subset of dispersed immune 'players' are rapidly recruited into a precisely targeted immune response, itself intricately orchestrated to produce an effective response to some organismal problem. The sharp, precise point of each immune response is the culmination of an immensely complex collection of interactions at multiple timescales and sub-organismal locations.

In this way, part (iii) of the YES schema engages immune complexity. Although there is much we don't know about the immune system and its connections to other bodily systems, the knowledge we do have is impressively detailed and can be deployed to great therapeutic benefit.

But, precisely because of those features, it's difficult for non-experts to understand immunology's explanations, methods, and concepts (Fagan 2023). The complexity of the immune system (as currently understand by experts) has multiple dimensions: diverse intra- and inter-cellular components, intricately choreographed interactions between bio-active molecules, physical factors, elaborate sub-organismal compartmentalization, and more. The system is dynamic, consisting of ongoing processes at multiple scales of biological organization, ranging from molecules to the whole organism. Mechanisms and pathways at these various scales are intricately connected and densely interactive. Key themes in recent accounts of immunity are interconnectedness and interactive complexity (see Section 2). Nothing in the immune system acts alone, and to single out one component as central would belie most of the scientific insights listed above. But directly engaging this complexity would make the schema less accessible – like the introductory treatments discussed in Section 3. Immune specificity in the sense of (iii) avoids overwhelming detail, while capturing essential features of the immune system's working via the idea of bounded complexity. Visualizing this structure gives an accessible picture of immune complexity, without demanding that non-experts learn the details (although, of course, they *can* do so). The image in Figure 1 is, in a way, the inverse of the bowtie structure proposed as a topological explanation of lymphocyte-mediated immunity (Huneman 2010, Jones 2014, Huneman 2018). Instead of multiple inputs and outputs converging into and radiating out from a single indispensable core, the immune system originates with the start of an organism's life and terminates in precisely targeted effects. In between is profligate, riotous complexity.

Each of (i-iii), as explicated here, is directly accessible for a general audience of non-experts: one's biological life, problem-solving, and a mass of complexity bounded by common origin and a specific end-point. The schema as a whole satisfies the four requirements of simplicity,

accessibility, addressing issues of autonomy and control, and mutuality. Each part contributes to solving the problem outlined in Section 3, rendering the concept obviously relevant to non-experts (part i), replacing "defense-strength" with "problem-solving to extend life" (part ii), and representing immune complexity in an accessible manner (part iii). Together, they offer a route to non-expert understanding of the immune system. The next section shows the schema's practical relevance and bearing on philosophical debates about understanding.

5. Vaccines and non-expert understanding

As noted, understanding how the immune system works is a prerequisite for understanding how vaccines work. The YES schema satisfies this prequisite, and so can contribute to better public understanding of vaccines. To be sure, its potential contribution is modest; the YES schema does not directly combat anti-vaccination efforts and deliberate misinformation campaigns. Even so, it's worth working through the schema's implications for non-expert understanding of vaccines. The reasoning is simple. The YES schema characterizes each immune response as directed toward a specific end-point (iii). A vaccine enhances immune effectiveness (ii) for one specific response – and that's all. A vaccine does not, as such, alter one's immune system in any major or central way. It does not – cannot – make one's immune system less one's own (i). Control of an organism's immune system cannot be separated from the continuously active bodily systems that sustain an organism's life. Instead, a vaccine acts in a way tied to the end-point of one specific immune response. It acts to accelerate that response, speeding up progress toward solving a specific problem for the organism: a particular infectious disease. Each vaccine is designed to prime a vaccinated organism's immune system so as to respond faster, and thus more effectively, to a specific infectious disease (e.g., a strain of 'flu virus). No immune system is perfect, and

most infectious diseases use some "trick" that allows them some advantage over most human immune systems. Vaccines work by tilting the playing field, so to speak, by speeding up the organism's immune response to that specific pathogen – nothing more. The immune response would occur in any case; a vaccine just speeds up its progress to the specific end-point that solves the organism's problem; i.e., being infected by a particular disease. (Immunotherapy for some forms of cancer works in a similar way, but tweaks immune specificity more than speed; it is more of an intervention on one's immune system, in this sense. This doesn't make one's immune system any less one's own, of course.[36]) The continuous, complex work of one's immune system is otherwise unaffected by one (or multiple) vaccines. The accelerated response is more effective, because it is quicker. But it's just one of the myriad ongoing activities of an organism's immune system.

This way of understanding vaccines is, like the YES schema itself, grounded on current immunological knowledge. From an immunological perspective, a vaccine is a human technology that engages with an organism's immune system so as to prevent disease. Vaccines are a strikingly effective technology. It's rare for a human intervention on a complex system to work so well. Vaccines are effective because they do so little. Crucially, they don't alter or interfere with an organism's immune system. Rather, a vaccine is an experimentally-calibrated nudge that directs that system's ongoing activity in a particular way, such that a vaccinated organism doesn't experience the disease toward which the vaccine is directed. A vaccine shifts an organism's internal physiological balance so the organism experiences no (or few) disease symptoms. That is, a vaccine alters the timing and rate of an organism's immune response to a

[36] Because cancer is a disease arising from one's own cells, concepts of "self" implicated in cancer and its therapies need deeper analysis than can be pursued in this paper. See Plutynski (2018).

pathogen so as to benefit the organism. In this respect, a vaccine is unlike a drug; it does not work by introducing some new chemical effector into the body. Instead, a vaccine directs one's own immune system in a very specific way, shifting the demographic balance of the pathogen/organism interaction. The upshot is that a vaccinated organism experiences no (or fewer) pathological symptoms upon encountering that pathogen. Vaccines are not in themselves central to one's ongoing immunity at all. Even dozens of vaccines amount to minor tweaks to one aspect of one of the immune system's many continuous activities that sustain an organism's life.

The three-part YES schema affords an accessible treatment of vaccines and how they work, encouraging non-expert understanding of this aspect of immunity too. Although this non-expert understanding is connected to our current best scientific understanding of the immune system, it is not the same as expert understanding. Yet there is no fundamental divide between the two; modes of understanding may be traversed as well as connected.[37] For interested readers, here is a bit more detail. One pathway of cell development initiated as part of some immune responses leads to "memory" B and T cells. These are long-lived cell types which have surface receptors specific for this problem – a specific pathogen. Unlike "naïve" B and T cells, memory cells of that specificity are more numerous and require less developmental time to initiate a second (or third, etc.) immune response. So an organism's response to a second, third (etc.) exposure to that pathogen is faster and of greater magnitude than the first. Vaccines' efficacy rests on this "adaptive" immune memory. The vaccine itself is a molecule (sometimes a macromolecular complex) designed to elicit a primary immune response to a specific pathogen

[37] Indeed, connections of the YES schema's sort can be built upon and enhanced, so as to enable easy transition from non-expert to expert understanding (or the reverse, in principle). See Fagan (2025).

that does not lead to health problems for the organism. The organism's immune system is thereafter ready with an enhanced response to any subsequent encounter with that pathogen – it "learns" from the vaccine to respond more effectively. Immune protection via vaccines ("immunity" in the classic sense) is conferred by the action of one's own immune system, not by any externally-imposed control or manipulation of one's body.

I'll conclude this essay with some broader philosophical implications of the YES schema. One, obviously, is that non-experts can understand science-based concepts in their own, epistemically beneficial way. It follows that scientific understanding of the immune system is not the only possible way to understand that bodily system. Distinct varieties of understanding of a common target can coexist. This is a form of pluralism about scientific understanding. If we take this pluralism seriously, it is worth characterizing non-expert understanding as a distinct variety. The four YES schema requirements offer some guidance. These are requirements for a conceptual framework that can afford non-expert understanding of science-based concepts. Such a framework must be simple, accessible, and mutually-connected to expert knowledge/understanding of the target. The need to address concerns of bodily autonomy and control is a feature of this case; immunity and the immune system. The more general counterpart to this is engagement with everyday experience and concerns. The general picture of non-expert understanding suggested by this case thus includes four requirements:

- simple (few moving parts)
- accessible (commonsense ideas and concepts; engaging everyday experience)
- addressing agents' concerns (responsive to issues arising in everyday experience)
- mutual connection with relevant expertise

Non-expert understanding of scientific concepts is inherently relational; it is understanding in relation to science. But the relation is mutual, not a one-way transmission as posited by the deficit model. Neither is non-expert understanding merely a pale and lagging imitation of expertise. Instead, it positively engages ideas and concerns in everyday experience. In the case of the immune system, the latter include not only health and well-being, but also bodily autonomy and control. A general theme in this view is that understanding is context-dependent, relative to a perspective.

These considerations suggest the following view of understanding; a sketch of a philosophical theory. Understanding is not unitary, but plural – there are varieties of understanding. Different kinds of understanding need not (cannot) be evaluated on a single axis of "better or worse," just as immune systems cannot be evaluated uniformly as "strong or weak." Connecting different varieties of understanding of some target is itself an epistemic achievement. This view of understanding is fully articulated and defended in my other work (Fagan 2017, 2020, 2025). The main insights of this paper are limited to the case of non-expert understanding of immunity and the immune system. Yet the case does suggest several ideas for future work. One task along these lines is to assess how this view of non-expert understanding bears on other philosophical theories currently on offer. I conclude with a few remarks, to set the stage for future work focused on that issue.

Most philosophical theories of scientific understanding do not directly address non-expert contexts. Nonetheless, at least some recent theories appear compatible with the view sketched here. The most obviously congenial are pluralist accounts that define "understanding" in terms of grasping regularities in the world, selectively attending to patterns that further agents' aims and projects (e.g., Elgin 2017, Potochnik 2017, Elgin 2025). Pluralist accounts of this sort would

seem to admit understanding relative to non-experts' aims and concerns, consonant with the YES schema. Similarly, Le Bihan's (2016) "modal understanding" is had by an agent of some phenomena just in case that agent "knows how to navigate some of the possibility space associated with these phenomena" (127).[38] Non-experts navigate different regions of possibility space than experts, but both, plausibly, have modal understanding. This seems fully compatible with implications of the YES schema. There is some tension with Elgin's theory, which defines an agent's understanding as grasping "a systematically linked body of information," with more articulated and explicit links within this body making for better understanding (2017, 44). Expert understanding of a science-based topic is always better than non-expert understanding, on this view. Yet Elgin's "ecological" approach to epistemology (2025), emphasizing fruitfulness and improvement over hierarchical judgments, is congenial to the socially-engaged project of this paper. Even more socially-engaged is Malfatti's (2025) theory, on which agents' understanding is socially-influenced and fits into personal experience, alongside conditions of "moderate factivity." There are many points of convergence between Malfatti's "social fabric of understanding" and the view indicated here, although their full exploration is a task for future work.

For contextual theories centered on scientific understanding, compatibility is not so obvious. For example, de Regt (2015, 2017) argues that scientists understand a phenomenon if they construct an explanatory model of that phenomenon using one or more intelligible theories. However, a non-expert analogue of de Regt's contextual theory could fit the YES schema well. As his view is specifically about scientific understanding, the option seems available. Similarly,

[38] "Possibility space" is "the set of possible dependency structures that give rise to all subsets of the phenomena and the relations between those structures" (ibid).

Wilkenfeld's contextual "representation manipulability" theory (2013) fits the YES schema quite well. On the former view, understanding consists in an agent's ability to manipulate a mental representation of some object, using counterfactual reasoning, so as to afford efficacious inferences about, or direct manipulations of, the object of understanding. Yet more recent elaborations of this theory (e.g., Wilkenfeld 2019) seem to privilege scientists and other experts, much like Elgin's. Kvanvig's influential (2003) coherence account also has an equivocal relation to YES' implications. On his view, "[u]nderstanding requires the grasping [piecing together] of explanatory and other coherence-making relationships in a large and comprehensive body of information" (192). Although Kvanvig's requirements suggest a need for expertise in the subject matter thereby understood, non-experts too can "piece together" diverse items of information into coherent systems. The network of metaphorical associations centered on YES could arguably be construed as a such a system. To sum up, a number of recent theories of understanding require that an agent be able to inferentially deploy a large and sophisticated body of information about a topic/phenomenon, or hierarchically rank agents' understanding as better or worse in these terms. It remains to be seen whether these points of contrast with the view non-expert understanding sketched here are deep theoretical conflicts, or artifacts of different philosophical approaches and methods.

For at least one influential theory of understanding, however, there is clear conflict with the view proposed here. On Khalifa's "explanation, knowledge, science" theory (2017) an agent understands a proposition p just in case that agent grasps a correct explanation of p, and their understanding is improved by adding more (accurate) explanatory information about p, or by

matching our best current scientific explanation of p.[39] It follows that non-expert understanding is inferior to expert scientific understanding. Although Khalifa's "threshold condition" allows for some degree of non-expert understanding, that degree is by definition less than that of expert understanding. While not implausible, especially for scientific concepts such as immunity, philosophers' emphasis on a hierarchy of understanding that uniformly privileges science seems ill-suited for practical, socially-engaged philosophical projects. So there is a genuine tension between the view proposed here, and at least some recent philosophical theories of understanding. This is not, of course, a rebuttal of Khalifa's theory. I've merely indicated the conflict, not how to resolve it. However, an insight from philosophy of immunology is worth considering in that regard. Just as "strong vs. weak" is too simple and univocal to convey an accurate idea of the immune system and its workings (see Sections 2 and 3), "understanding" may be too multi-faceted to be adequately captured by a simple "better vs. worse" axis. The view proposed here treats non-expert understanding of science as a species of interdisciplinary connection, opening up more dimensions for evaluation and critique. Rather than a rebuttal, this view offers a challenge for Khalifa's theory, and others committed to a single evaluative axis for understanding. Why not admit multiple aspects of understanding, some better-suited to some contexts than others? Fully articulating and responding to this challenge is a task for future work.

6. Conclusion

[39] Khalifa's theory also ranks agents' understanding, such that agent S_1 understands a proposition p better than another agent S_2 if and only if "(A) c*eteris paribus*, S_1 grasps *p's* explanatory nexus more completely than S_2; or (B) *ceteris paribus*, S_1*'s* grasp of *p's* explanatory nexus bears greater resemblance to scientific knowledge than S_2*'s*" (2017, 14).

In nearly all public-facing or policy-oriented discussions, and many scientific ones, the immune system appears as an inscrutable black box. This is reasonable; in many contexts, it makes sense to keep a lid on immunological complexity. But it would also be good to have a simple, accessible account of the immune system at the ready. The defense-strength metaphor is simple and accessible, and widespread in everyday contexts. But it leads to problems. Many common misunderstandings of immunity stem from and are supported by the "strong vs. weak" framing. These misunderstandings are augmented by associated analogies with muscle tissue as well as everyday notions of causation and control. It's reasonable for non-experts to use these ideas to make sense of immunity and the immune system in everyday life. That many do so is evidenced by everyday talk about immunity matters of lifestyle, health, wellness, and vaccination (notably vaccination of children). In this way, the defense-strength metaphor contributes to current public conflicts about vaccines and science policy more broadly. To replace this problematic metaphor and its network of misleading associations, I've proposed a schema for non-expert understanding of immunity and the immune system: the YES schema.

The YES schema (yours, efficient, specific) is a simple conceptual framework that recognizes immune complexity, without requiring its audience to engage that complexity directly. An organism's immune system is inalienably its own, necessary for life and entangled with its ongoing physiological processes and systems ("yours"). The immune system functions to solve problems for an organism, extending its healthy lifespan ("efficient"). It manages this via myriad immune responses, each of which is specific to a particular problem-solving episode. The targeted point of each such response is shown in Figure 1, which limns the 'shape' of an organism's immune system activity: origin-point, intricate dynamic complexity, sharpening to a specific end-point of response ("specific"). Unlike introductory STEM treatments of the immune

system, this schema is simple, recognizing immune complexity without delving into details. It satisfies requirements for non-expert understanding of this esoteric scientific subject, being simple, accessibly engaging everyday experience, addressing concerns about autonomy and control, and related to scientific insights via mutual connection rather than one-way transmission. The case of immune understanding shows how philosophers of biology can deploy their expertise to address broader social problems and science-society relations. This account of non-expert understanding also has implications for ongoing philosophical debate on that topic, although full exploration of these ideas is a task for future work.

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References

Bernard C (1878) Leçons sur les phénomènes de la vie communs aux animaux et aux vegetaux, Paris, Bailliere JB. Translated by JF Fulton, in *Selected Readings in the History of Physiology*, p.308.

Brown, N (2019) Immunitary Life: A Biopolitics of Immunity. Palgrave Macmillan

Bryce, E, Grosso, F, Seixas, O, Laufquen, S, Max, P (2018) How does your immune system work? TED-Ed Animation, TED Conferences LLC < https://ed.ted.com/lessons/how-does-the-immune-system-work-emma-bryce >

Burnet, FM, and Fenner, F (1949) The Production of Antibodies, 2nd edition. Macmillan

Clarke, E (2025) The Units of Understanding. Oxford University Press

Cohen, E (2009) A Body Worth Defending. Duke University Press

de Regt, H (2015) Scientific understanding: truth or dare? Synthese 192: 3781–3797

de Regt, H (2017) Understanding Scientific Understanding. Oxford University Press

Eberl, G (2016) Immunity by equilibrium. Nature Reviews Immunology 16: 524-532

Elgin, CZ (2017) True Enough. MIT Press

Elgin, CZ (2025) Epistemic Ecology. MIT Press

Fagan, MB (2017) Explanation, multiple perspectives, and unification. Balkan Journal of Philosophy 9: 19-34

Fagan MB (2020) Interdisciplinarity, perspectives, and explanation. In: Massimi, M, and McCoy, CD (eds.) Understanding perspectivism: Scientific Challenges and Methodological Prospects, Taylor and Francis, 28-49

Fagan, MB (2023) Immunology and human health: collaboration without convergence. Philosophy of Science 90: 1265-1275

Fagan, MB (2024) Moving beyond explanatory monism. In: *The Routledge Handbook of Causality and Causal Methods.* F Russo and P Illari (eds), Routledge, 433-444

Fagan, MB (2025) Explanatory Particularism in Scientific Practice. Oxford University Press

Fagan, MB, and Schneider, T (in preparation) Philosophy of immunology. To appear in: Comprehensive Philosophy of Science, Hansson, SO (ed); Philosophy of Biology, Merlin, F (ed), Elsevier

Faggioni, T … et al Virtual immunology: an educational software to encourage antigen-antibody interaction learning. Advances in Physiology Education 46: 109–116, 2022

Goldenberg, M (2016) Public misunderstanding of science? Perspectives on Science 24: 552-581

Harvard Health Letter (2025) How to boost your immune system: helpful ways to strengthen your immune system and fight off disease. Harvard Health Publishing of The President and Fellows of Harvard College

Hesse, M (1966) Models and Analogies in Science. Notre Dame University Press

Huneman, P (2010) Topological explanations and robustness in biological sciences. Synthese 177: 213- 245.

Huneman, P (2018) Diversifying the picture of explanations in biological sciences: ways of combining topology with mechanisms. Synthese 195:115-146.

Janeway (1992) The immune system evolved to discriminate infectious nonself from noninfectious self. Immunology Today 13: 11-16

Jones, N (2014) Bowtie structures, pathway diagrams, and topological explanation. Erkenntnis 79: 1135-1155.

Khalifa, K (2017) Understanding, explanation, and scientific knowledge. Cambridge: Cambridge University Press

Khan, S (2021) Overcoming Vaccine Hesitancy. Master's Thesis, University of Arizona

Klein, J (1982) Immunology: The Science of Self-Nonself Discrimination. Wiley

Kovaka, K (2015) Biological individuality and scientific practice. Philosophy of Science 82: 1092-1103

Kvanvig, JL (2003) The Value of Knowledge and the Pursuit of Understanding. Cambridge University Press

Land, W, and Messmer, K (1996) The impact of ischemia/reperfusion injury on specific and non-specific, early and late chronic events after organ transplantation. Transplantation Reviews 10: 108-127

Le Bihan, S (2016) Enlightening falsehoods: a modal view of scientific understanding. In: Grimm, SR, Baumberger, C, Ammon, S (eds.) Explaining Understanding. Routledge: Taylor and Francis, 127-152

Löwy, I (1992) The strength of loose concepts – boundary concepts, federative experimental strategies and disciplinary growth: the case of immunology. History of Science 30: 371-396

Malfatti, FI (2025) The Social Fabric of Understanding. Springer.

Martin, E (1994) Flexible Bodies. Boston: Beacon Press

Matzinger, P (1994). Tolerance, danger, and the extended family. Annual Review of Immunology 12: 991-1045

Matzinger, P (2002) The danger model. Science 296: 301-305

Moulin, A-M (1989) Immunology old and new: the beginning and the end. In: Mazumdar, PMH (Ed.). Immunology 1930-1980: Essays on the History of Immunology (pp. 291-298)

Neocleous M (2022) The Politics of Immunity: Security and the Policing of Bodies. Verso

Paul, WE (1983) Preface to Volume 1. *Annual Review of Immunology* 1: vii

Plutynski, A (2018) Explaining Cancer: Finding Order in Disorder. Oxford University Press

Potochnik, A (2017) Idealization and the Aims of Science, Oxford University Press

Pradeu, T (2012) The Limits of the Self: Immunology and Biological Identity. New York: Oxford University Press, translated by Elizabeth Vitanza

Pradeu, T (2019) Cambridge Elements: Philosophy of Immunology. Cambridge University Press

Pradeu, T, Thomma, BPHJ, Girardin, SE, and Lemaitre, B (2024) The conceptual foundations of innate immunity. Immunity 57: 613-631

Reynolds, A (2017) The Third Lens. University of Chicago Press

Rice, C (2021) Leveraging Distortions. MIT Press

Rimer J, Cohen IR, Friedman N (2014) Do all creatures possess an acquired immune system of some sort? BioEssays 36: 273–281

Rollins, J (2021) Front-line fatigue. KSL.com, KSL Broadcasting, Deseret Digital Media, posted - Oct. 10, 2021; updated - Oct. 11, 2021

Schneider, T (2021) The holobiont self: understanding immunity in context. History and Philosophy of the Life Sciences 43: 99, doi 10.1007/s40656-021-00454-y

Silverstein, AM (1989) *A History of Immunology*. San Diego: Academic Press

Swiatczak, B, and Tauber, AI (2020) Philosophy of Immunology. The Stanford Encyclopedia of Philosophy (Summer 2020 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/sum2020/entries/immunology/>.

Tauber, AI (1994) The Immune Self: Theory or Metaphor? Cambridge University Press

Tauber, AI, and Chernyak, L (1991) Metchnikoff and the Origins of Immunology. Oxford University Press

Tauber, AI (2017) Immunity: the Evolution of an Idea. Oxford University Press

Waddington, CH (1939) *An Introduction to Modern Genetics*. New York: MacMillan

Weasel, L (2001) Dismantling the self/other dichotomy in science: towards a feminist model of the immune system. Hypatia 16: 27-44

Welsh, E, and Updyke, EA (2019) This podcast will kill you. Episode 26, May 16, 2019. Transcript at: <https://thispodcastwillkillyou.com/wp-content/uploads/2021/06/TPWKY-Episode-26-Vaccines-I.pdf>

Wilkenfeld, D (2013) Understanding as representation manipulability. Synthese 190: 997-1016

Wilkenfeld, D (2019) Understanding as compression. Philosophical Studies 176: 2807-2831

Zach, M, and Greslehner, G (2023) Understanding immunity: an alternative framework beyond defense and strength. Biology & Philosophy 38:7 https://doi.org/10.1007/s10539-023-09893-2