Are Biology Experts and Novices Function Pluralists?

Andrew J. Roberts[1,2] · Pierrick Bourrat[1,2,3]

© The Author(s) 2024

Abstract
Philosophers have proposed many accounts of biological function. A coarse-grained distinction can be made between backward-looking views, which emphasise historical contributions to fitness, and forward-looking views, which emphasise the current contribution to fitness or role of a biological component within some larger system. These two views are often framed as being incompatible and conflicting with one another. The emerging field of synthetic biology, which involves applying engineering principles to the design and construction of biological systems, complicates things further by adding intentional design as a source of function. In the current study we explored how biology experts and novices think about function in the context of single-celled, multi-celled, and synthetic organisms. We also explored the extent to which each group were function pluralists, and if they were function pluralists, which accounts of function tended to be endorsed together. The results showed a surprising degree of similarity between experts and novices in most contexts, although certain differences were apparent. Most surprisingly, we found evidence not only of function pluralism in both groups, but pluralism between backward-looking and forward-looking accounts. We discuss these findings in the context of the philosophical debate on function and consider the practical implications for public acceptance of synthetic biology. First, we argue that philosophers of biology should re-examine the purported incompatibility between accounts of function. Second, we argue that due to the introduction of an intentional aetiology in synthetic biology, there may be an inherent conflict between the views of experts and novices when thinking about synthetic biology.

Extended author information available on the last page of the article

🙅 Springer

1 Introduction

Philosophers have proposed many accounts of biological function, and all purport to capture the way that biologists talk about function. These accounts of biological function can be grouped in several ways, but a coarse-grained distinction can be made between backward-looking and forward-looking views. Backward-looking views claim that the function of any biological component is defined by how it improved the relative fitness of ancestor organisms (e.g., Godfrey-smith 1994; Griffiths 1993; Millikan 1989; Neander, 1991; Wright 1973). For example, the fact that ancient light-detector cells allowed certain organisms to respond to the day-night cycle, meant these organisms had an advantage over others and had more offspring. Over time, the proportion of ancestor organisms that had light-detector cells increased. Within this ancient population, those organisms with slightly better light-detector cells had more offspring than those with slightly worse light-detector cells. Gradually, light-detector cells came to resemble modern eyes. The function of sight is not just what eyes do; it is the reason why eyes currently exist.

Forward-looking views, on the other hand, claim that function is defined by what a biological component currently contributes to the organism. There are many forward-looking views of function, including those that emphasise some contribution to a larger system within the organism (e.g., Cummins 1975; Mossio et al. 2009, 2013), those that emphasise the current contribution (or propensity to contribute) to the fitness of the organism (e.g., Bigelow and Pargetter 1987; Boorse 1977), and those that emphasise the seemingly goal-directed nature of biological processes (e.g., Braithwaite 1953; Nagel 1977). In the current paper, we explore whether philosophical accounts of function accurately capture the beliefs of biologists and non-biologists, and we investigate how different beliefs about function may fit together.

1.1 Selected Effects

Philosophers are rarely in agreement with one another. Amongst those favouring the backward-looking Selected Effect view, there is disagreement over the timescale involved in historical contributions to fitness resulting from the function of a biological component (e.g., Garson 2019; Godfrey-smith 1994). In other words, should the historical contribution to fitness be a recent one, and if so, what constitutes recent? Selected Effect theorists also disagree over how proximal or distal the function can be from the trait. For example, is the function of the heart to pump (proximal to the heart), or is the function of the heart to circulate blood throughout the body (distal to the heart)? There is also disagreement over the extent to which selection applies only to reproduction versus persistence (Bourrat 2021; Garson 2016b). If selection can be generalised beyond reproduction to allow for differential rates of persistence, then where does this stop? Presumably, neuronal pruning could be considered a form of selection (Garson 2019), but as Bourrat (2021) points out, if this were true, then there is no principled reason why selection should not also apply to a pile of rocks on a beach.

Despite these points of disagreement, there are several advantages to defining the function of a biological trait in terms of past selection rather than its current contri-

bution to a larger system, its propensity to confer a relative fitness advantage to the organism, or its seemingly goal-directed nature. First, by tying the notion of function to past selection, the Selected Effects account can distinguish a function from a lucky accident. For example, the function of the heart is to pump blood rather than to make beating sounds, because it was pumping blood– not making beating sounds– that caused hearts to be selected for in the past. The fact that a heart condition may be diagnosed by listening to beating sounds is just a lucky accident. Second, by virtue of the fact that the Selected Effects account is explicitly backward-looking, it can answer the question of why (or how) hearts came to exist in a way that forward-looking accounts cannot. Finally, by tying the notion of function to past selection, Selected Effects are normative. If a particular heart is not performing the function that hearts were selected for, then that heart is not functioning correctly. As many Selected Effect theorists have argued, forward-looking views of function fall short on one or more of these points (Christie et al. 2022; Garson 2016a, 2019; Neander 1991a; Wright 1976).

The Selected Effect account is not without its critics. A common criticism of tying the notion of function to past selection is a perceived reliance on "just so" narratives– particularly in the context of evolutionary psychology– because we can only ever *infer* past evolutionary pressures (Gould and Lewontin 1979). Furthermore, as Christie et al. (2022) point out, when a function is defined by historical selection pressures, the result is often a narrative that provides an overly-simplistic view of evolution by failing to account for frequency-dependent selection (but see Okasha 2022). However, while these are valid criticisms of the way that biologists (and others) sometimes refer to selected effects, they are not criticisms of the basic idea of selected effect functions per se: that is, the idea that biological traits exist today because of what they did in the past.

1.2 The Boundary of Biology

The philosophical debate on function has been further complicated by a blurring of the traditional boundaries of what it means for something to be biological compared to artefactual. The recently emerging field of synthetic biology applies engineering principles to the development of biological components and systems (CSIRO 2021) aimed at addressing societal challenges, such as the production of food, medicine, or technologies aimed at environmental protection (Gray et al. 2018; Mankad et al. 2021). As engineering principles are applied to biological systems *so that* these systems address some societal challenge, the concept of function is central to synthetic biology (e.g., Meng and Ellis 2020). However, by applying engineering principles to biological systems, synthetic biology takes the product of evolution and introduces an element of intentional design. In doing so, synthetic biology blurs the line between what is natural and what is artefactual (Holm 2013).

As others have noted, a traditional Selected Effect view of function (e.g., Godfreysmith 1994; Griffiths 1993; Neander 1991b) seems to provide an inadequate account of synthetic biological systems (e.g., Holm 2014, 2016; Holm and Powell 2013). This does not necessarily mean that an aetiological account of function is incompatible with synthetic biology, as the aetiologies of artefacts are the intentions of the

designer. If one was to remain agnostic as to the type (or source) of aetiology, then an account such as Wright's (1976) consequence aetiology, which applies to both natural selection and intentional design, may be appropriate. However, under this view, it would be possible for the two aetiologies (natural selection and intentional design) to produce conflicting functions if a designer altered part of an organism with the intention that it does something other than its Selected Effect function.

A potential solution to the problem of functions in synthetic biology has been to focus less on aetiologies, and more on the role of a biological component within some larger system. Organisational accounts of function hold, roughly, that the function of any biological component can be defined by what that component contributes to some larger system, and in making that contribution, how the component ensures the conditions necessary for its own continued existence within the organism (Mossio et al. 2009, 2013; Mossio and Bich 2017). By focusing on the role of a biological component within a larger system, it has been argued that an organisational account can accommodate both naturally evolved and artefactual functions, while avoiding the potential conflict between the two (Holm 2012). However, given that the field of synthetic biology has emerged only recently, and perhaps due, in part, to the interdisciplinary nature and multitude of approaches used in synthetic biology (Gray et al. 2018), it is unclear whether an organisational account of function captures the way that biologists and other experts think about function in synthetic biology. It is also unclear whether these groups differ in their function beliefs in other contexts: specifically, whether beliefs about function in biology vary according to scale (i.e., single-celled vs. multi-celled). Our motivation for investigating whether beliefs about function vary according to the scale of the organism, is that the more complex the system, perhaps the more likely people are to explain that system in terms of goal-directed behaviour.

1.3 Function Pluralism

Based on a review of the literature, one could be forgiven for thinking that there exists a single correct account of function. However, several theorists have argued for "function pluralism" in one form or another (Garson 2017; Kitcher 1993; Millikan 1998; Roux 2020). Function pluralism is the idea that when people talk about functions, they may mean different things on different occasions. That is, there may be more than one "correct" view of function, and what is correct depends on the context.

A distinction has been made between two forms of function pluralism (e.g., Garson 2016a): Between-discipline pluralism, which holds that certain accounts of function are relevant for certain disciplines of biology, and within-discipline pluralism, which holds that scientists within a given discipline mean different things at different times when they talk about function. Although a detailed discussion of these two views is beyond the scope of the current paper, it appears that both views do not exhaust the way one could be a function pluralist. In both forms of function pluralism seems to be the idea that a person cannot believe in two or more views of function simultaneously. That is, when a person says that the function of the heart is to pump blood, they are *sometimes* referring to historical selection pressures and *sometimes* referring to the role of the heart within the larger circulatory system of the organism,

but never both at the same time. Here we propose that a third way of being a function pluralist would be to hold such different beliefs at the same time. There is indeed some empirical evidence that people can sometimes hold seemingly contradictory or incompatible beliefs at the same time (de Neys et al. 2011; Pennycook et al. 2015). To date, there is very little empirical evidence about whether people are function pluralists, and if they are, what form of function pluralism they endorse. It is even less clear if the idea of function pluralism applies to synthetic biology, and again, if it does, in what form.

1.4 Current Study

In the current study, we remain agnostic about which account of function or which form of pluralism biology experts or complete novices should endorse. Rather, we aim to determine the "goodness of fit" between philosophical accounts of function and the beliefs of these groups. Specifically, we explore the following questions:

1. Do experts differ from novices in their beliefs about biological function?
2. Do experts differ from novices in the extent to which they are function pluralists?
3. If experts or novices are function pluralists, which accounts of function cluster together under which circumstances?
4. How do experts and novices think about function in the context of synthetic biology?

2 Methods

2.1 Ethics Statement

This study was granted ethical clearance by the Macquarie University Human Research Ethics Committee (approval number 38,068).

2.2 Participants

We recruited from two distinct populations. First, to investigate how people *without* tertiary qualifications in biology (i.e., no university-level qualifications in biology) think about function, we recruited 101 undergraduate Psychology students.[1] These participants received course credit in exchange for participating in the study. After exclusion based on an attention check, 97 participants remained. In this group, there were 17 males, 79 females, and one non-binary person (M_{age} = 23.4, SD_{age} = 9.6, $Median_{age}$ = 19).

---

[1] We recruited Psychology students for two reasons. First, these students need to take part in research to receive course credit. This means we were able to recruit these participants at no cost. Second, as a sizable proportion of human research uses Psychology students as participants, we reasoned that this would make it easy for researchers to compare our findings with future studies investigating beliefs about function.

Second, to investigate how people *with* formal tertiary qualifications or expert knowledge in biology think about function, we recruited 121 participants using three methods. Ninety participants with post-graduate qualifications in biology (i.e., Master or PhD) were recruited from the online service, Prolific. These participants received payment of £2.25 in exchange for participating in the 15-minute study. We also recruited 19 participants involved in the "Agency, Directionality & Function" project as part of the "Science of Purpose Initiative" (funded by the John Templeton Foundation) and 12 participants from the Centre of Excellence in Synthetic Biology (funded by the Australian Research Council). Participants in these two groups did not receive payment in exchange for participation. After exclusion based on an attention check, 101 participants remained in our sample of biologists ($n_{prolific}$ = 71, n_{jtf} = 18, n_{coe} = 12). Within this group, there were 53 males, 47 females, and one non-binary person (M_{age} =33.66, SD_{age} = 12.48, $Median_{age}$ = 28). All participants self-reported being fluent in English.

There was very little prior research on which to base estimates of effect size to determine the required sample size. However, a sensitivity analysis performed in G*Power (Faul et al. 2007) revealed that our sample of 97 novices and 101 experts (N=198) would allow us to detect a small-to-medium effect size of d=0.40 when comparing between groups, and a small effect size of d=0.20 when comparing within-groups, both with power of 0.80 and an alpha of 0.05[2].

2.3 Materials

We presented participants with three questions to assess their beliefs about biological function:

1. "After millions of years of evolution, yeast cells contain mitochondria that produce energy. Consider the statement, "*the function of mitochondria in yeast is to produce energy*". What makes this statement true?"
2. "After millions of years of evolution, most animals have hearts. Consider the statement, "*the function of the heart is to pump blood*". What makes this statement true?"[3]
3. "Scientists have engineered *E. coli* to contain photoreceptors that can convert light into energy through photosynthesis. Consider the statement, "*the function of photoreceptors in E. coli is to produce energy*". What makes this statement true?"

---

[2] Our initial plan was to recruit additional participants from the CoESB and JTF groups, but we struggled with recruitment. Ethical constraints meant we had to limit the number of times we approached these individuals to ask them to take part in our study. This meant we needed to supplement our sample of experts by recruiting through the paid service, Prolific.

[3] We would like to thank an anonymous reviewer for drawing our attention to the fact that the question about hearts is not strictly equivalent to the other questions, as it does not mention "pumping blood" in the first sentence. The reason we felt it necessary to provide additional information in the other two questions, was that participants in our novice sample may not have known what mitochondria or photoreceptors do. However, we reasoned that all participants would know what hearts do.

After each question, participants were shown seven propositions in random order and told to select all that they agreed with. The seven propositions, corresponded to:

1. a naïve account (i.e., "*the function of x is just what z does*").
2. an intentional account (i.e., "*the function of x is what z was created to do*").
3. a goal-directed account (i.e., "*the function of x helps to achieve the goal of y*").
4. a fitness contribution account (i.e., "*by doing x, z contributes to the reproductive fitness of the organism*").
5. a causal-role account (i.e., "*by doing x, z contributes to the performance of other systems in the organism*").
6. an organisational account (i.e., "*by doing x, z contributes to their own survival by keeping the organism alive*").
7. a selected effect account (i.e., "*doing x was beneficial in the past, and that is why z was selected for*").

Provided a participant agreed with more than one of these propositions, they were then asked to select their favourite.

2.4 Procedure

This study was part of a larger project on beliefs about function. Upon giving informed consent, participants were first presented with a series of 12 vignettes describing scenarios in which the current functions of biological components were either congruent or incongruent with the selected effect function. This part of the study is not discussed further in the current paper[4]. Next, participants were presented with the three questions described in the previous section in a random order. They then provided demographic information of age and gender. To ensure participants were reading the questions carefully, the final part of the study asked them to select both 4 and 6 from a 7-point Likert scale. Any participant who did not select both 4 and 6 was excluded from the study.

3 Results

3.1 Function Pluralism

As shown in Table 1, within each content type, the mean number of views of function endorsed by undergraduates and biology experts was remarkably similar. Independent samples t-tests showed no significant differences between undergraduates and experts in the number of views endorsed for single-celled organisms (t(195.37)=1.28, p=.201, d=0.182), multi-celled organisms (t(195.04) = -0.98, p=.328, d = -0.140),

---

[4] We would like to thank the editor for drawing our attention to the fact that the preceding task may have affected the current results. As the vignettes described current functions that were either congruent or incongruent with a selected effect function, this may have had the effect of making the selected effect functions more salient in the current study.

Table 1 Mean number of views of function endorsed for each group

		Single-celled	Multi-celled	Synthetic
Novices	M	3.2	3.7	3.1
	SD	1.7	1.7	1.7
Experts	M	3.5	3.5	3.1
	SD	1.8	1.6	1.7

Note. Means can range from 1 to 7, with higher numbers representing a more pluralistic understanding of function

Table 2 Percentage of each group agreeing with the different views of function

	Naïve	Intentional	Goal Directed	Fitness	Causal Role	Organisational	Selected Effect
Single-celled							
Novices	53.6	39.2 a	59.8	49.5	51.5 b	46.4 c	22.7 d
Experts	50.5	19.8 a	46.5	60.3	66.3 b	61.4 c	49.5 d
Multi-celled							
Novices	42.3	46.4 e	68.0 f	56.7	73.2	66.0 g	17.5 h
Experts	50.5	30.7 e	49.5 f	53.5	70.3	49.5 g	42.6 h
Synthetic							
Novices	43.3	50.5	49.5	50.5	52.6	47.4	16.5
Experts	36.6	59.4	44.6	46.5	53.5	38.6	26.7

Note. Novices *n*=97, Experts *n*=101. Within each of the three content types, views of function with the same subscript are significantly different at *p*<.05 using a chi-square test

or synthetic biology (*t* (195.99) = -0.18, *p*=.856, *d* = -0.026). However, paired-samples t-tests revealed significant differences in endorsement rates within groups across the three content types (single-celled, multi-celled, and synthetic organisms). Undergraduates accepted significantly more views of function for multi-celled organisms compared to both single-celled organisms (*t* (96)=3.23, *p*=.001, *d*=0.281), and synthetic biology (*t* (96)=3.90, *p*<.001, *d*=0.355). Biology experts accepted significantly more views of function for single-celled (*t* (100)=3.64, *p*<.001, *d*=0.272) and multi-celled organisms (*t* (100)=2.88, *p*=.004, *d*=0.238) than they did for synthetic biology. These findings suggest that both groups tended to be less pluralistic in their views of function for synthetic biology than for non-synthetic biology. See the supplementary materials for distributions of endorsement rates and correlations between endorsement rates across each content type.

Despite not finding any significant differences between groups in the number of views endorsed within each of the three content types, there were certain differences in the specific views that each group was drawn to. As shown in Table 2 (note that different subscripts denote statistical significance), for single-celled organisms, novices were more accepting than biology experts of an intentional view of function, and experts were more accepting than novices of the causal-role, organisational, and selected-effect views of function. For multi-celled organisms, novices were more accepting than experts of the intentional, goal-directed, and organisational views of function, and again, experts were more accepting than novices of a selected-effect view of function. Surprisingly, for synthetic biology, we found no significant differences between biology experts and novices.

3.2 Relationships between Views of Function

Having found that, despite certain differences, both groups of participants endorsed a form of function pluralism, next we explored how the different views of function related to one another. Acceptance of a view of function could plausibly vary along a continuum (i.e., a person could vary between strongly rejecting and strongly accepting a view of function). However, given that we measured acceptance as a dichotomous outcome (either rejected or accepted), instead of using Pearson or Spearman correlations, we performed tetrachoric correlations using the Psych package in R (Revelle 2023). Tetrachoric correlations describe the relationship between two continuous variables, each of which have been measured using dichotomous scales (Bonett and Price 2005).

As shown in Table 3, for views of function about single-celled organisms, in both groups there were significant negative relationships between endorsing a naïve view of function and endorsing an organisational view of function. In both groups, there were also significant positive relationships between endorsing a fitness contribution view and the causal role view, the organisational view, and the selected effect view. Most notably, experts saw the selected effect account as compatible with several forward-looking accounts, including both the causal role and organisational accounts. Surprisingly, experts who endorsed the selected effect view of function also tended to be more accepting of an intentional view of function.

As shown in Table 4, for multi-celled organisms, experts and novices showed a remarkably similar pattern of beliefs. For both groups, a naïve view of function was positively related to an intentional view of function. Both groups also showed a clustering of beliefs, with significant positive relationships between the goal directed view and both the causal role and organisational views, and between the fitness contribution view and the causal role, organisational, and selected effect views. In contrast to beliefs about single-celled organisms, for experts, there were no significant

Table 3 Relationships between views of function for single-celled organisms

Experts	Naïve	Intentional	Goal	Fitness	Causal	Organisational
Naïve	-					
Intentional	0.43**	-				
Goal	0.08	0.32*	-			
Fitness	−0.18	0.18	0.23	-		
Causal	−0.12	0.39**	0.52***	0.88***	-	
Organisational	−0.28*	0.07	0.27	0.59***	0.68***	-
Selected Effect	−0.02	0.45**	0.05	0.48***	0.39**	0.46**
Novices	Naïve	Intentional	Goal	Fitness	Causal	Organisational
Naïve	-					
Intentional	0.24	-				
Goal	−0.01	0.30*	-			
Fitness	0.08	0.08	0.28*	-		
Causal	0.01	−0.11	0.40**	0.56***	-	
Organisational	−0.27*	0.03	0.07	0.36**	0.37**	-
Selected Effect	0.02	0.21	0.08	0.35*	0.40**	0.15

Note. Tetrachoric correlations with significance (* $p<.10$; ** $p<.05$; *** $p<.01$)

Table 4 Relationships between views of function for multi-celled organisms

Experts	Naïve	Intentional	Goal	Fitness	Causal	Organisational
Naïve	-					
Intentional	0.57***	-				
Goal	−0.02	0.32	-			
Fitness	−0.02	0.03	0.14	-		
Causal	−0.06	0.10	0.54***	0.35**	-	
Organisational	−0.32**	0.46**	0.38**	0.32**	0.20	-
Selected Effect	0.14	−0.09	0.05	0.31**	0.13	0.11
Novices	Naïve	Intentional	Goal	Fitness	Causal	Organisational
Naïve	-					
Intentional	0.45**	-				
Goal	0.01	−0.04	-			
Fitness	0.05	0.29*	0.33*	-		
Causal	0.16	0.16	0.65***	0.57***	-	
Organisational	0.14	0.05	0.53***	0.33*	0.34*	-
Selected Effect	0.28	0.21	0.17	0.35*	0.35*	0.09

Note. Tetrachoric correlations with significance (* $p<.10$; ** $p<.05$; *** $p<.01$)

Table 5 Relationships between views of function for synthetic organisms

Experts	Naïve	Intentional	Goal	Fitness	Causal	Organisational
Naïve	-					
Intentional	0.14	-				
Goal	−0.03	0.27*	-			
Fitness	0.12	−0.12	0.49***	-		
Causal	0.25	−0.32**	0.43**	0.53***	-	
Organisational	0.02	0.06	0.48**	0.49***	0.39**	-
Selected Effect	0.17	0.01	0.50***	0.33**	0.34**	0.48**
Novices	Naïve	Intentional	Goal	Fitness	Causal	Organisational
Naïve	-					
Intentional	−0.01	-				
Goal	0.40**	0.24	-			
Fitness	0.05	−0.30*	0.30*	-		
Causal	0.06	−0.24	0.18	0.56***	-	
Organisational	0.01	−0.02	0.27*	0.48***	0.31*	-
Selected Effect	0.21	0.20	0.22	0.52***	0.06	0.45**

Note. Tetrachoric correlations with significance (* $p<.10$; ** $p<.05$; *** $p<.01$)

positive relationships between the selected effect view of function and an intentional, causal role, or organisational view of function.

Finally, the relationships between views of function for synthetic biology are shown in Table 5. Immediately obvious are the significant positive relationships for experts between the goal directed, fitness contribution, causal role, organisational, and selected effect views. Despite the notion of artefactual function arguably being relevant to synthetic biology, we only found evidence of an intentional view of function being negatively related to the causal role view (for experts) and the fitness contribution view (for novices). Even though the intentional and selected effect views

seem to offer different explanations for the origin of traits (one being the result of an intentional agent and one being the result of natural selection), these appear to be orthogonal in terms of beliefs, with no significant relationship found between these views for either group of participants[5].

3.3 Favoured View of Function

The preceding sections show that biology experts and novices are function pluralists. That is, for a given biological trait, people tend to agree with multiple accounts of function. In the current section, we explore what happens when people are forced to choose just one view of function. As shown in Table 6 (note that different subscripts denote statistical significance), there is a degree of consistency between favoured views of function and rates of acceptance when people are allowed to select all the views they agree with. Specifically, for both single-celled and multi-celled organisms, biology experts tended to favour the selected effect view of function to a greater extent than novices did. In contrast to our findings on function pluralism, for single-celled organisms, experts and novices did not differ significantly in the percentage favouring an intentional view of function. Likewise, for multi-celled organisms, experts and novices did not differ significantly in the percentage favouring a goal directed view of function, but there was a significant difference in the percentage favouring an organisational view, with novices favouring this view significantly more than experts. Of most interest are the findings on synthetic biology. In contrast to the findings on function pluralism, which showed no significant difference between experts and novices in rates of acceptance across views of function for synthetic biology, when looking at the favoured view, a pattern emerged. While the novices showed no clear preference (with the exception, perhaps, of overwhelmingly rejecting a selected effect view), the biology experts favoured an intentional view of func-

Table 6 Favoured view of function expressed as a percentage of each group

	Naïve	Intentional	Goal Directed	Fitness	Causal Role	Organisational	Selected Effect
Single-celled							
Novices	15.5	5.2	26.8	11.3	14.4	24.7	2.1 a
Experts	13.9	5.0	21.8	10.9	10.9	20.8	16.8 a
Multi-celled							
Novices	4.1	10.3	20.6	5.2	25.8	30.1 b	3.1 c
Experts	10.9	5.9	22.8	8.9	22.8	15.8 b	12.9 c
Synthetic							
Novices	10.3	19.6 d	19.6	15.5	18.6	14.4	2.1 e
Experts	10.9	34.7 d	10.9	13.9	9.9	10.9	8.9 e

Note. Novices $n=97$, Experts $n=101$. Within each of the three content types, cells with the same subscript are significantly different at $p<.05$ using a chi-square test

---

[5] We thank the editor for drawing our attention to this point. Although it might seem like different explanations for the origin of a trait should produce beliefs that are orthogonal, our intuition was that there would be a negative relationship between the two accounts. To see why, consider the debate between evolutionists and creationists. These beliefs are not independent. If a person endorses creationism, they are less likely to believe in natural selection.

tion for synthetic biology. This shows that although this group may be pluralistic in their view of function, not all accounts of function are seen as equal.

4 Discussion

For all the nuanced accounts of biological function in the philosophical literature, surprisingly little is known about whether biology experts and novices share an appreciation of these differences. The current study aimed to address this gap by examining the differences and similarities in beliefs about biological function between those with formal qualifications and expert knowledge in biology, and those without. Specifically, we investigated the extent to which both groups were function pluralists across three contexts (single-celled, multi-celled, and synthetic organisms), how the various philosophical accounts of function clustered together for each group of participants, and which account of function either group favoured when forced to choose.

Our results highlighted three key findings. First, our results showed that regardless of formal training or expert knowledge in biology, people tended to be function pluralists[6]. Across the three contexts (single-celled, multi-celled, and synthetic biology), we found no evidence to suggest that formal training or expert knowledge in biology affects function pluralism[7]. However, when examining differences in function pluralism across contexts within groups, some differences emerged. Novices tended to be less pluralistic in their view of function for single-celled organisms and synthetic biology compared to multi-celled organisms, whereas experts tended to be more pluralistic in their view of function for single-celled and multi-celled organisms compared to synthetic biology. What is surprising about these results is not just the degree of similarity between experts and novices, but the type of function pluralism this supports. While certain disciplines of biology may, on average, favour one view of function over another, the current results provide evidence not only for within-discipline function pluralism, but for within-person function pluralism. That is, any given person may simultaneously accept several accounts of function for a single biological trait.

One area where this finding could be potentially relevant is the controversy surrounding the ENCODE project. This project aimed at identifying all the functional elements of the human genome. In 2012, ENCODE researchers concluded that over 80% of our genome is functional (ENCODE consortium, 2012). This claim stood in contrast to the prevailing view, that most of our DNA was effectively "junk" in terms of its contribution to our survival and reproduction. The claim that over 80% of our genome is functional was soon criticized (Doolittle 2013). Critics argued that the 80% could only be reached if a causal role account of function was implicitly used

---

[6] As highlighted by an anonymous reviewer, not all "function monists" should be expected to pick only one view. For example, Boorse's goal-directed account equates the contribution to some goal with a contribution to fitness. Therefore, if someone was to agree only with the view put forth by Boorse, they should endorse both a goal-directed and fitness-contribution account of function.

[7] To be clear, we are not surprised that Psychology students have intuitions about function in biology. We are surprised that beliefs about function do not seem to change as the result of formal training in biology.

by ENCODE researchers. Instead, critics claimed, biologists typically refer to the selected effect account. Since then, several attempts have been made to adjudicate which account of function should be used when assessing what part of the human genome is functional (Brzović and Šustar 2020; Germain et al. 2014; Linquist et al. 2020). Our first finding shows that this type of enterprise might be hampered by the existence of within-person function pluralism. A second key finding was the pattern of relationships between accounts of function when people were given permission to be function pluralists. In contrast to most of the philosophical literature which paints a picture of division between the Selected Effect account and forward-looking accounts, the current results suggest that this is not how experts and novices think. Overall, the results shown in Tables 3 and 4, and 5, show that people who accept the Selected Effects account of function are *more* likely to also accept fitness contribution and system contribution views of function compared to those who did not accept the Selected Effects account. This is entirely consistent with work suggesting that in practise, biologists integrate system contribution and evolutionary accounts of function (Cusimano and Sterner 2019; Roux 2014; Sterner et al. 2023). Put simply, backward-looking accounts and forward-looking accounts are seen not only as compatible, but complementary.

A third key finding was the low rate of acceptance for Selected Effect functions in experts. When participants were forced to choose a single account of function for single-celled and multi-celled organisms, fewer than 17% of biology experts favoured Selected Effects. Even when participants were allowed to agree with multiple accounts of function, fewer than 50% of experts endorsed a Selected Effect account. Given that "*the ultimate source of explanation in biology is the principle of natural selection*" (Ayala 1970), it is surprising that so few people with post-graduate qualifications and expertise in this field based their view of function in natural selection[8].

4.1 Implications and Future Directions

Although, for current purposes, we remained agnostic about what people "should" think about function, our findings do suggest somewhat of a disconnect between the philosophical debate on function and ordinary usage of the term. Garson (2016a; p. 12) states that "*as philosophers of biology, we should try to construct a theory of function that, first and foremost, makes sense of the way that biologists use the term (both their implicit and explicit commitments)*". We agree with Garson on the importance of constructing a theory of function that captures how biologists think and argue that the current findings show there is still work to be done. Rather than claiming that the subtle differences of seemingly competing philosophical accounts of function are unimportant, we simply argue that these differences are not necessarily seen as incompatible to the non-philosopher. Given the importance of making sense

---

[8] As highlighted by an anonymous reviewer, it is possible that to expert biologists, saying "a trait exists because it is a consequence of past selection pressures" may be true, but trivial. We also acknowledge a point made by a second anonymous reviewer, that the word "favourite" is ambiguous and may have been interpreted differently by different participants.

of the way that biologists use the term, philosophers of biology should re-examine whether competing accounts of function are competing indeed. In the current study, we found evidence to suggest that backward-looking and forward-looking accounts of function are compatible. An important next step will be to test how these beliefs fit together. For example, forward-looking accounts may be seen as compatible with backward-looking accounts in that they provide a continuation of the historical fitness contribution[9].

In stating the aim of constructing a theory of function, Garson (2016a) also draws a distinction between implicit and explicit commitments. An implicit commitment to Selected Effects, according to Garson, involves "*using the notion of function with explanatory and normative connotations*", such that people may be "*implicitly appealing to selection, even if they do not realise that this is what they are doing*" (p. 50). We agree with Garson that people sometimes make implicit commitments to a theory that they do not make explicit, although we question whether using the notion of function with explanatory and normative connotations should be taken as evidence of such commitments. Even when a biological trait is explained by its Selected Effect function, the result is often to provide an over-simplified account of natural selection (Christie et al. 2021). Here, when explicitly referring to Selected Effects, biologists may be making implicit commitments that they simply do not have the time (or word-count) to make explicit (Okasha 2022). However, it is difficult to reconcile Garson's position with the current findings. As participants simply had to choose accounts of function they agreed with (rather than generate an explanation themselves), it seems a stretch to claim that they were implicitly appealing to selection despite having not agreed with this account.

The current findings also highlight an important point that needs to be considered in relation to public opinion on synthetic biology. When participants were able to select multiple accounts of function to explain a component of a synthetic biological organism, we observed no significant differences between biologists and non-biologists in acceptance across the various accounts. However, when forced to choose, the difference was clear. Whereas the novices showed no preference for any account of function in this context, biology experts tended to be drawn towards an intentional account of function. That is, experts tended to base their view of function in intentional design, whereas novices did not. One possible explanation for this could be that those without formal training in biology tend to display some form of psychological essentialism (i.e., the belief that biological entities have an underlying, unchanging essence that is unobservable; Gelman 2004). Studies have shown that this way of thinking is already present in early childhood (Cimpian and Salomon 2014; Diesendruck and Haber 2009; Gelman and Wellman 1991). Given that endorsing an intentional account of function in synthetic biology requires a person to represent an organism as a kind of artefact, this likely presents a challenge to those

---

[9] We acknowledge that this is an oversimplification due to the differences across the various accounts of function. Simply "providing a continuation of historical fitness" may not explain the compatibility between all forward-looking and backward-looking views. Relatedly, it would be possible to defend a position where a backward-looking account is subordinate to a forward-looking account (i.e., where historical contributions to fitness are seen as hypotheses generated from observing current contributions to fitness). We thank the editor and an anonymous reviewer for these suggestions.

who have essentialist tendencies. To test this, future studies should test whether an intentional view of function in synthetic biology positively correlates with essentialist beliefs in other contexts.

Although the materials in the current study were created in such a way as to contain no conflict between the "natural" and "artefactual" (i.e., intended) functions, this may not always be the case. Suppose that the naturally occurring function of a biological component is to do x, but a biologist alters this component with the intention that it no longer does x, but instead does y. This seems to be a situation in which we are forced to choose between two functions, and the current results suggest that biology experts and novices may not agree on what the function is. To understand the implications of this, consider the following: If a biologist is successful in intentionally altering a biological component so that it no longer does x but instead does y, then to the biology expert, by doing y, that component is functioning correctly. However, to the novice, by doing y instead of x, that component is now dysfunctional. Put another way, what is seen as success to the biology expert may be seen as failure to the novice.

Those working in this field already recognise the need to avoid a similar public backlash to that associated with the genetic modification of agricultural commodities in the past (Carter and Mankad 2021). Consistent with previous research highlighting public concerns about "playing God" or "tampering with nature" in synthetic biology (Carter et al. 2021), the current findings contribute to this literature by showing the potential for conflict when intentional design and nature meet. An important next step for social scientists working in synthetic biology will be to investigate how people think about function when a conflict between artefactual and natural function is introduced. If, as we have suggested here, the public gravitate towards the natural rather than artefactual function (whether due to essentialist tendencies or for other reasons), it will be important to explore strategies aimed either at modifying these underlying beliefs or at framing synthetic biology as a solution to a problem in such a way as to encourage uptake (e.g., Kahneman et al. 1979; Tversky and Kahneman 1981). In doing so, it may be useful to consider beliefs about natural vs. artefactual function in synthetic biology within a dual-processes theory framework (De Neys 2014; Pennycook et al. 2015). Whereas traditional dual-process models viewed logical reasoning as an effortful process (Evans 2007), recent evidence shows that people are sensitive to the logical validity of arguments regardless of their response to the argument (Purcell et al. 2023). In other words, to be aware of the logical validity of simple arguments does not necessarily require effort. In the current context, this suggests that providing participants with simple arguments in favour of artefactual functions in synthetic biology, may be one method of aligning the beliefs of the public with those of biologists.

5 Conclusion

The current study provides empirical evidence about how biology experts and non-experts think about the concept of function across three contexts. Our findings challenge existing accounts of function pluralism by showing that multiple theories of function, including backward-looking and forward-looking theories, are endorsed

simultaneously by the same individual for the same biological trait. Beyond accounts dealing specifically with function pluralism, these findings also provide a challenge to philosophers aiming to create a theory of function that captures how biology experts talk about function more generally. Far from viewing the Selected Effect account as incompatible with the Causal Role, Fitness Contribution, or Organisational accounts, experts view these as complementary. The current study also shows that biology experts are more likely than non-experts to view synthetic biology as having artefactual as opposed to natural functions. This, we argue, is likely to have implications for public support of synthetic biology as a solution to the big problems. Facilitating public acceptance of synthetic biology will require social scientists and philosophers to work together towards the common goal of aligning views of function across different groups of people.

Data Availability Raw data and R code for analysis are available on the Open Science Framework (https://osf.io/br6sf/?view_only=ed8cf87f6c4b4b5b822a3fba180f68d2).

Declarations

Competing Interests The authors have no competing interests to declare.

References

Ayala, F. J. 1970. Teleological explanations in evolutionary biology. *Philosophy of Science* 37(1): 1–15. https://doi.org/10.4324/9781351048521-5.

Bigelow, J., and R. Pargetter. 1987. Functions. *The Journal of Philosophy* 84(4): 181–196.

Bonett, D. G., and R. M. Price. 2005. Inferential methods for the tetrachoric correlation coefficient. *Journal of Educational and Behavioral Statistics* 30(2): 213–225. https://doi.org/10.3102/10769986030002213.

Boorse, C. 1977. Health as a theoretical concept. *Philosophy of Science* 44(4): 542–573.

Bourrat, P. 2021. Function, persistence, and selection: generalizing the selected-effect account of function adequately. *Studies in History and Philosophy of Science* 90(August): 61–67. https://doi.org/10.1016/j.shpsa.2021.09.007.

Braithwaite, R. B. 1953. *Scientific explanation: a study of the function of theory, probability, and law in science*. Cambridge University Press.

Brzović, Z., and P. Šustar. 2020. Postgenomics function monism. *Studies in History and Philosophy of Biological and Biomedical Sciences* 80: 101243. https://doi.org/10.1016/j.shpsc.2019.101243.

Carter, L., and A. Mankad. 2021. The promises and realities of Integration in Synthetic Biology: a View from Social Science. *Frontiers in Bioengineering and Biotechnology* 8(January): 1–5. https://doi.org/10.3389/fbioe.2020.622221.

Carter, L., A. Mankad, E. V. Hobman, and N. B. Porter. 2021. Playing God and tampering with nature: Popular labels for real concerns in synthetic biology. *Transgenic Research* 30(2): 155–167. https://doi.org/10.1007/s11248-021-00233-2.

Christie, J. R., C. Brusse, P. Bourrat, P. Takacs, and P. E. Griffiths. 2021. *Are biological traits explained by their selected effect functions?* 1–28.

Christie, J. R., Z. Wilkinson, S. A. Gawronski, and P. E. Griffiths. 2022. *Concepts of function in biology and biomedicine*. https://doi.org/10.1046/j.1420-9101.1999.0002j.x.

Cimpian, A., and E. Salomon. 2014. The inherence heuristic: an intuitive means of making sense of the world, and a potential precursor to psychological essentialism. *Behavioral and Brain Sciences* 37(05): 461–480. https://doi.org/10.1017/S0140525X13002197.

CSIRO. 2021. *A national synthetic biology roadmap*.

Cummins, R. 1975. Functional analysis. *The Journal of Philosophy* 72(20): 741–765.

Cusimano, S., and B. Sterner. 2019. Integrative pluralism for biological function. *Biology and Philosophy* 34(6): 1–21. https://doi.org/10.1007/s10539-019-9717-8.

De Neys, W. 2014. *Dual process theory 2.0* (W. De Neys (ed.)). Routledge.

de Neys, W., S. Cromheeke, and M. Osman. 2011. Biased but in doubt: conflict and decision confidence. *Plos One* 6(1). https://doi.org/10.1371/journal.pone.0015954.

Diesendruck, G., and L. Haber. 2009. God's categories: the effect of religiosity on children's teleological and essentialist beliefs about categories. *Cognition* 110(1): 100–114. https://doi.org/10.1016/j.cognition.2008.11.001.

Doolittle, W. F. 2013. Is Junk DNA Bunk? A Critique of ENCODE. *Proceedings of the National Academy of Sciences*, *110*(14), 5294–5300. https://doi.org/10.1073/pnas.1221376110.

Evans, J. S. B. T. 2007. On the resolution of conflict in dual process theories of reasoning. *Thinking & Reasoning* 13(4): 321–339. https://doi.org/10.1080/13546780601008825.

Faul, F., E. Erdfelder, A. G. Lang, and A. Buchner. 2007. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods* 39(2): 175–191. https://doi.org/10.3758/BF03193146.

Garson, J. 2016a. A critical overview of biological functions. *Springer International Publishing*. https://doi.org/10.1007/978-3-319-32020-5.

Garson, J. 2016b. A generalized selected effects theory of function. *Philosophy of Science* 18(2): 22280. https://doi.org/10.1016/j.neps.2015.06.001https://www.abebooks.com/Trease-Evans-Pharmacognosy-13th-Edition-William/14174467122/bd

Garson, J. 2017. How to be a function pluralist. *British Journal for the Philosophy of Science* 10(2): 184–189. https://doi.org/10.1111/j.1746-8361.1956.tb00337.x.

Garson, J. 2019. *What biological functions are and why they matter*. 1st ed. Cambridge University Press.

Gelman, S. A. 2004. Psychological essentialism in children. *Trends in Cognitive Sciences* 8(9): 404–409. https://doi.org/10.1016/j.tics.2004.07.001.

Gelman, S. A., and H. M. Wellman. 1991. Insides and essences: early understandings of the non-obvious. *Cognition* 38(3): 213–244. https://doi.org/10.1016/0010-0277(91)90007-Q.

Germain, P. L., E. Ratti, and F. Boem. 2014. Junk or functional DNA? ENCODE and the function controversy. *Biology and Philosophy* 29(6): 807–831. https://doi.org/10.1007/s10539-014-9441-3.

Godfrey-smith, P. 1994. A modern history theory of functions. *Nous* 28(3): 344–362.

Gould, S. J., and R. C. Lewontin. 1979. The spandrels of San Marco and the panglossian paradigm: A critique of the adaptationist programme. *Proceedings of the Royal Society of London B, Biological Sciences*, *205*(1161), 581–598.

Gray, P., S. Meek, P. Griffiths, J. Trapani, I. Small, C. Vickers, C. Waldby, and R. Wood. 2018. *Synthetic biology in Australia: An outlook to 2030*.

Griffiths, P. E. 1993. Functional analysis and proper functions. *British Journal for the Philosophy of Science* 44(3): 409–422. https://doi.org/10.1093/bjps/44.3.409.

Holm, S. 2012. Biological interests, normative functions, and synthetic biology. *Philosophy and Technology* 25(4): 525–541. https://doi.org/10.1007/s13347-012-0075-6.

Holm, S. 2013. Organism and artifact: proper functions in Paley organisms. *Studies in History and Philosophy of Biological and Biomedical Sciences* 44(4): 706–713. https://doi.org/10.1016/j.shpsc.2013.05.018.

Holm, S. 2014. Disease, dysfunction, and synthetic biology. *Journal of Medicine and Philosophy (United Kingdom)* 39(4): 329–345. https://doi.org/10.1093/jmp/jhu025.

Holm, S. 2016. Is synthetic biology mechanical biology? *Journal of Materials Science: Materials in Medicine* 27(1): 413–429. https://doi.org/10.1007/s40656-015-0081-y.

Holm, S., and R. Powell. 2013. Organism, machine, artifact: the conceptual and normative challenges of synthetic biology. *Studies in history and philosophy of Science Part C:studies in*. *History and Philosophy of Biological and Biomedical Sciences* 44(4): 627–631. https://doi.org/10.1016/j.shpsc.2013.05.009.

Kahneman, D., A. Tversky, and A. Tversky '. 1979. Prospect theory: an analysis of decision under risk. *Econometrica* 47(2): 263–292. http://www.jstor.org/stable/1914185%5Cnhttp://www.jstor.org/%5Cnhttp://www.jstor.org/action/showPublisher?publisherCode=econosoc.%5Cnhttp://www.jstor.org

Kitcher, P. 1993. Function and design. *Midwest studies*. *Philosophy* 18(1): 379–397. https://doi.org/10.1111/j.1475-4975.1993.tb00274.x.

Linquist, S., W. F. Doolittle, and A. F. Palazzo. 2020. Getting clear about the F-word in Genomics. *PLOS Genetics* 16(4): e1008702. https://doi.org/10.1371/journal.pgen.1008702.

Mankad, A., E. V. Hobman, and L. Carter. 2021. Effects of knowledge and emotion on support for novel synthetic biology applications. *Conservation Biology* 35(2): 623–633. https://doi.org/10.1111/cobi.13637.

Meng, F., and T. Ellis. 2020. The second decade of synthetic biology: 2010–2020. *Nature Communications* 11(1): 1–4. https://doi.org/10.1038/s41467-020-19092-2.

Millikan, R. G. 1989. In defense of proper functions. *Philosophy of Science* 56(2): 288–302.

Millikan, R. G. 1998. Wings, spoons, pills, and quills: a pluralist theory of function. *Journal of Philosophy* V(October): 226765.

Mossio, M., and L. Bich. 2017. What makes biological organisation teleological? *Synthese* 194(4): 1089–1114. https://doi.org/10.1007/s11229-014-0594-z.

Mossio, M., C. Saborido, and A. Moreno. 2009. An organizational account of biological functions. *British Journal for the Philosophy of Science* 60(4): 813–841. https://doi.org/10.1093/bjps/axp036.

Mossio, M., L. Bich, and A. Moreno. 2013. Emergence, Closure and Inter-level Causation in Biological systems. *Erkenntnis* 78(SUPPL2): 153–178. https://doi.org/10.1007/s10670-013-9507-7.

Nagel, E. 1977. Functional explanations in biology. *The Journal of Philosophy* 74(5): 280–301.

Neander, K. 1991a. Functions as selected effects: the conceptual analyst's defense. *Philosophy of Science* 58(2): 168–184. https://doi.org/http://www.jstor.org/stable/187457.

Neander, K. 1991b. The teleological notion of function. *Australasian Journal of Philosophy* 69(4): 454–468. https://doi.org/10.1080/00048409112344881.

Okasha, S. 2022. *Function in the Light of Frequency-Dependent Selection*. *March*, 1–34.

Pennycook, G., J. A. Fugelsang, and D. J. Koehler. 2015. What makes us think? A three-stage dual-process model of analytic engagement. *Cognitive Psychology* 80: 34–72. https://doi.org/10.1016/j.cogpsych.2015.05.001.

Purcell, Z. A., A. J. Roberts, S. J. Handley, and S. Howarth. 2023. Eye Movements, Pupil Dilation, and conflict detection in reasoning: exploring the evidence for intuitive logic. *Cognitive Science* 47(6). https://doi.org/10.1111/cogs.13293.

Revelle, W. 2023. *Psych: Procedures for Psychological, Psychometric, and Personality Research* (2.3.6). Northwestern University. https://cran.r-project.org/package=psych.

Roux, E. 2014. The Concept of function in modern physiology. *The Journal of Physiology* 592(Pt 11): 2245–2249. https://doi.org/10.1113/jphysiol.2014.272062.

Roux, E. 2020. Are biological functions selected effects? *Metascience* 29(1): 107–111. https://doi.org/10.1007/s11016-020-00492-5.

Sterner, B., S. Elliott, and J. G. Wideman. 2023. An account of conserved functions and how biologists use them to integrate cell and evolutionary biology. *Biology and Philosophy* 38(5): 1–23. https://doi.org/10.1007/s10539-023-09933-x.

Tversky, A., and D. Kahneman. 1981. The framing of decisions and the psychology of choice. *Science* 211(4481): 453–458.

Wright, L. 1973. Functions. *The Philosophical Review* 82(2): 139–168.

Wright, L. 1976. *Teleological explanations*. University of California Press.

Authors and Affiliations

Andrew J. Roberts[1,2] · Pierrick Bourrat[1,2,3]

✉ Pierrick Bourrat
  p.bourrat@gmail.com

[1] Department of Philosophy, Macquarie University, Sydney, Australia

[2] ARC Centre of Excellence in Synthetic Biology, Sydney, Australia

[3] Department of Philosophy & Charles Perkins Centre, The University of Sydney, Sydney, Australia