The values of synthetic biology:

researcher views of their field and participation in public engagement

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Abstract

The synthetic biology research community will influence the future development of synthetic biology and its emergence into the sociopolitical and regulatory arenas. Because of this influence, we provide a first look at those involved in the research field – their views regarding the field and interactions with the public – using a unique sample of U.S.-based researchers who have published in the broad field of synthetic biology. Our data indicates a range of views of the moral and regulatory aspects of the science, based in part on various values and professional judgements, with differences emerging across synthetic biologists (e.g., bench scientists, computer scientists) and researchers focusing on ethical, legal, and social implications (ELSI). Importantly, the researchers are engaged in public outreach activities, which could provide opportunities for public discourse on the sociopolitical aspects of synthetic biology. Implications of these findings for the future of the technology and upstream engagement emerge.

Keywords: synthetic biology, values, public engagement, regulations

Synthetic biology and its applications raise social, ethical, and regulatory questions that often do not have clear or exclusively scientific answers (Achenbach 3 May 2016). Although many of these questions matter for members of the public, they also have tremendous implications for scientists directly involved in synthetic biology research. Given the significant role that the research community will play in guiding not just research but also regulatory agendas surrounding synthetic biology, it is surprising how little we empirically know about what researchers in this area think of the technology[1] and its sociopolitical, regulatory, and ethical implications. Toward that end, we developed a unique sample of U.S.-based researchers connected to the field of synthetic biology, including bench scientists, computer scientists, and those focusing on the ethical, legal, and social implications (ELSI) of the science. As further described below, our sample is specialized to those who have published on topics associated with synthetic biology from 2000 to 2015. These researchers were surveyed to capture their views on the field and its regulation, as well as their involvement in public engagement. The results reveal a range of views on the moral and regulatory considerations of synthetic biology that appears to vary depending on researchers' values and how they contribute to the field (i.e., their professional judgments as synthetic biologists or ELSI researchers). Across this mix of views, the majority of the researchers report engaging, at least infrequently, with the public on their work. Together, these results suggest that synthetic biologists approach their own field from multiple perspectives, that they are aware of the ethical context of their work, and that they may be willing to engaging in public-expert discourse on synthetic biology.

[1] Here, we refer to synthetic biology interchangeably as a science and technology, in part because of the range of research areas and applications included in the field. Notably, those in the science and technology studies (STS) categorize synthetic biology as a "technoscience" (Latour 1987) to represent the intertwining science and technology that shape the research and applications. We have opted away from this term to be accessible to a wider audience.

Scientists, values, and engagement

As a wide range of synthetic biology applications continue to emerge, so do concerns with their societal implications. In many ways, synthetic biology can be considered a "wicked problem" (Rittel and Webber 1973), requiring policy or regulatory decisions that include trade-offs among many technical, political, and ethical considerations. Many of the policy debates surrounding synthetic biology, therefore, will depend on input from scientists, policy makers, public stakeholders, and industry, and all their different value systems, policy preferences, and understandings, to negotiate the appropriate role of these applications in society (e.g., Delgado et al. 2011, Evans and Plows 2007, Stirling 2014).

Scholars in science and technology studies have long studied the values that intertwine with science from an in-depth, case-by-case perspective (Feyerabend 1993, Jasanoff 1990a, 2005, Keller 1983, 1991, Latour and Woolgar 1986). Scientists and decision-making processes surrounding the implications of scientific research and applications are not immune from the influences of values. For example, scientists routinely rely on their political ideology, which often represents a particular set of values, when making judgments about regulatory options affecting their own field of expertise (Corley et al. 2009), even if their training means they are "professionally committed to impartiality" in their own research (Jasanoff 1990b). While those in the critical science and technology studies have focused on representing the complexities involved in the formation of scientific attitudes for the public and experts alike, further research has approached this intersection of expert views and values from other methodological perspectives. For example, social science researchers have demonstrated expert reliance on values when forming opinions about their own work for nanoscientists using survey-based quantitative research (Corley et al. 2009, Ho et al. 2011). In bringing these fields of study

together, we gain a fuller understanding of the role of values for scientists: science and technology studies demonstrates the complexity surrounding expert views of their science, while the latter research can identify patterns and relationships for experts across disciplines. Such fields of study are not incompatible, but have different yet interdependent purposes.

Additional research on scientific experts and decisions regarding the implementation of science in society has focused on what information, considerations, or people matter for these decisions. Expert groups have historically run the risk of representing what the public believes to be too narrow a pool of considerations in societal issues involving science (Hogan 2016, Hurlbut 2015, Slovic et al. 1991, Tesh 1988). In cases of controversial science issues, the public at least implicitly recognizes that many of the implications are not answerable by science alone and that scientists and experts can have very different values and views on the implications than do other stakeholders. Public engagement, therefore, is often expected from the public and increasingly called for from expert groups as well (NASEM, 2017, Scheufele et al. 2017).

In recognition of this, researchers have called for the integration of ethical and social considerations in policy decisions (Bedau et al. 2009, Brian 2015, Bubela et al. 2012, Krimsky 1982). Notably, researchers from the fields of synthetic biology and other genetic technologies have attempted to address ethical and moral considerations of such technologies through self-regulation, including the Asilomar Conference on Recombinant DNA (Berg et al. 1975) or Synthetic Biology (SB) 2.0 (Maurer 2012, Parens et al. 2009). Although such attempts at self-regulation have been praised within the scientific community (Barinaga 2000), they have also raised concerns for not including a wide-enough group of stakeholders or considerations (Barkstrom 1985, Jasanoff 2005, Jasanoff et al. 2015, Weiner 1999). Early data on synthetic biologists' views of regulations, as well, suggested that most of these researchers themselves

recognized a need for a mixed regulatory framework, including contributions from international guidelines, national laws, self-regulation, and "participatory approaches" involving stakeholders and members of the public (Ganguli-Mitra et al. 2009). Within the scientific community, acknowledgment of ESLI considerations and the need for public deliberation and engagement regarding new technologies emerges across a variety of recent issues, including emerging gene editing technologies (e.g., human genome editing, Mathews et al. 2015, Meagher and Lee 2016, NASEM, 2016, 2017). This burgeoning trend toward public involvement in science and technology decisions can be seen within the synthetic biology field as well (e.g., Akin et al. 2017, King and Webster 2009, Marris and Rose 2010). Over the last decade, numerous workshops, symposia, meetings, and advisory groups focusing on the sociopolitical considerations of synthetic biology have included members who approach the field from a variety of backgrounds, ranging from members of the public to synthetic biologists themselves (e.g., biological or computer sciences) and ELSI researchers (European Commission Directorate General for Health & Consumers 2010, International Risk Governance Council 2010, OECD 2014).

In this environment of entangled science and policy (Scheufele 2014), it is particularly important to understand how researchers connected to the field of synthetic biology are forming attitudes and making decisions about their field, and how often they participate in public engagement. As researchers in the broad field respond to calls for public engagement and participate in policy-making processes, the nuanced views and activities of researchers are key to public opinion formation and the future of the field. Our results offer an initial systematic examination of those working in the field of synthetic biology, including basic science researchers and ELSI researchers. Of note, while we felt it was important to include both those

involved in research on the science itself and those studying ELSI of the field, we consider them separately within this study due to the substantial differences in how they interact with the field, as well as their professional training. The separate analyses of these two groups of researchers are not intended as points for comparison, but to enable a better understanding of each of these groups and their potential contributions to public engagement. By focusing on how these researchers view synthetic biology, particularly the moral aspects, our analysis provides an overview of the "state of the field" to help navigate areas of scientist and public engagement in sociotechnical decision-making as they emerge.

Present research

The data presented in this paper are part of a study focusing on published researchers who work in the field of synthetic biology. The purpose of the study was to examine the researchers' perceptions of their field and the role of public engagement. The research questions this analysis addresses are: 1) what factors influence researchers' views of the moral acceptability of synthetic biology, 2) what factors influence researchers' views of synthetic biology regulations, and 3) how involved are synthetic biologists in public engagement and outreach efforts?

For the purposes of this study, we define synthetic biology as "the creation of new biological parts and systems and the redesign of natural biological systems for application in medicine and therapy, chemical production, energy production and storage, environmental clean-up, agriculture, robotics, and nanomaterials, among other areas" (definition adapted from others, see Synthetic Biology Project n.d.). Just as the field itself encompasses a wide range of

applications, a broad definition enabled us to include synthetic biologists and ELSI researchers from a diverse pool of research areas.

To accurately represent scientists working in the field of synthetic biology, the sample of researchers surveyed in the study is based on who had recent publications in the field. After developing a list of specific synthetic-biology related terms (see supplemental material for the full list), a Web of Science publication keyword search compiled relevant publications within the field of synthetic biology. The search results were then used to compile a list of U.S.-based researchers who have published in the synthetic biology field from January 2000 to October 2015. After removing duplicates, the final contact list was 1,748 researchers and 46.1 percent of those contacted completed the survey. The survey was administered primarily online, between November 2015 and January 2016, and conducted in multiple waves: a mailed introduction letter with an incentive, an email invitation to an online survey, two reminder emails to complete the online survey, followed by a final mailed reminder that included a print survey for non-responders (Dillman et al. 2014). In their completed surveys, the few respondents who indicated that they did not work in any area of synthetic biology were subsequently removed, resulting in a final sample of 790 respondents, 8% of whom completed a mail survey instead of the online survey.

The keyword search on Web of Science included a wide range of researchers who have published on topics related to synthetic biology in recent years, meaning the sample included both those who work on more traditionally defined synthetic biology research – such as lab or bench research in biological or computer science fields – and those who work with the ethical, legal, and social aspects. To acknowledge differences in research focuses, the sample was sorted into two groups: synthetic biologists and ELSI researchers.

The two groups were determined based on the researchers' responses to a survey question about the area of research they worked in. Synthetic biologists included those who indicated they worked in the following areas: agriculture and food, alternative energy, computer science, human health and medicine, military and defense, robotics or artificial intelligence, and basic science or research. ELSI researchers were those working in three different areas: social science, legal or ethical, and human enhancements. If a respondent selected multiple areas of research, those who chose any ELSI area were only included in that group to see if those who professionally work in ethical and social areas – even if the ELSI experience supplements work in other fields – have different views of the field based on their experiences than do those who chose not to select any ELSI research areas.

We use hierarchical ordinary least squares (OLS) analyses to predict the moral acceptability of synthetic biology (*morally acceptable*) and views on existing regulations of synthetic biology research and applications (*regulation research* and *regulation applications*).

Measures

The following variables were included in the models. *Gender* is coded as a dummy variable (1 = "female;" 19% female). *Academic age* is captured with a measure asking, "In what year did you complete your Ph.D., M.D., or D.V.M.?" Responses were subtracted from 2016 to provide an estimate of how many years each researcher has been active in their field (M = 20.3, SD = 12.4).

Risk and *benefit perceptions* are each single-items with a 5-point scale, asking respondents to indicate whether they agree or disagree with the statement, "Synthetic biology is risky/beneficial for society" (1 = "Strongly disagree" to 5 = "Strongly agree;" *risk*: M = 2.35, SD = 0.97; *benefit*: M = 4.07, SD = 0.67).

Religiosity is a single-item measure on an 11-point scale asking, "How much guidance does religion provide in your everyday life?" (0 = "No guidance at all;" 10 = "A great deal of guidance;" M = 2.4, SD = 3.28). *Political ideology* was determined by asking the following pair of items on a 5-point scale (1 = "Very liberal" to 5 = "Very conservative"): (1) "In terms of economic issues, would you say you are …?" and (2) "In terms of social issues, would you say you are …?" The items were then averaged to create a composite score of *political ideology* (M = 2.2, SD = 0.78, Pearson's r = 0.45, $p < .001$).

The *moral acceptability* of synthetic biology was measured as a single item on a 5-point scale asking respondents to what extent they agree or disagree that, "Synthetic biology is morally acceptable" (1 = "Strongly disagree," 5 = "Strongly agree;" M = 4.11, SD = 0.73). The sufficiency of existing *regulations for research* and *regulations for applications* of synthetic biology are each single item measures on a 5-point scale asking respondents whether they agree or disagree that "Existing regulations for synthetic biology research (applications) are sufficient" (1 = "Strongly disagree," 5 = "Strongly agree;" *Research*: M = 3.31, SD = 0.87; *Applications*: M = 2.94, SD = 0.90).

Limitations

Some limitations of this study warrant mentioning before presenting our results. There was a large difference in sample size between synthetic biologists (N=732) and ELSI researchers (N=57). The sample naturally included more of those who conducted research building the science itself because we included all those who have published in the broad field of synthetic biology, which includes many subdisciplines, while we captured only those ELSI researchers who have published on the specific topic. The types of analyses used are robust to differences in sample size. Additionally, our OLS analyses include only two control variables: academic age

and gender. We limited our analyses to including these controls for three reasons. First, because our focus was on professional views of their field of study, we included variables that are directly related to professional development (academic age) or that are known to have key impacts on views of technologies (gender). Second, our focus is on exploring the potential influence of values, which are typically included in such models as low-level predictors due to their influence on a wide range of other variables. Third, the factors we included in the model are in part based on past research on scientists' views of their fields, regulations, or ethical responsibilities (nanotechnology, Corley et al. 2013, 2016, Corley et al. 2009, Su et al. 2016). While limited past survey-based research has focused specifically on exploring the role of values for scientists forming views on their field, we include gender, academic age, and professional judgements of risks and benefits as control variables that are common and significant predictors across previous studies on related topics. Finally, survey-based research inherently requires a reduction in the complexity of views surrounding complex topics, such as views about science and technology; however, what we lose in complexity, we gain in testing how different concepts relate. Among other reasons, this points to the necessity of multiple methological approaches: although not the purose of survey-based research, other fields of study can account for and detail the complexities surrounding these topics. As others have pointed out for research about public understanding of science, the integration of multiple methods, approaches, and fields is the best way forward (Bauer et al. 2007).

The "state of the field"

Before discussing the factors that contribute to how the researchers view the moral acceptability of the technology (RQ1) and how they view its regulation (RQ2), we overview who

these researchers are and their views of synthetic biology. On average, the researchers who took part in our study were middle-aged (M = 49.2, SD = 12.2), male (81%), white (75%), non-religious (50% report no guidance from religion in their daily lives), and politically liberal for both economic (52%) and social (76%) issues. They average 20 years of experience in their fields (academic age M = 20.3, SD = 12.4). Based on the areas of research that respondents indicated they worked in, the majority of researchers were classified as synthetic biologists (93%; which includes working in agriculture and food, human health and medicine, robotics, and basic science and research), rather than ELSI researchers (see *Present research* for more details on the classification). Focusing on demographic traits, synthetic biologists and ELSI researchers differed substantially. Synthetic biologists were politically liberal for economic (52%) and social (75%) issues, white (74%), and reported low levels of religious guidance (51% non-religious), while more ELSI researchers were included in each of these categories (64% liberal for economic issues; 87% liberal for social issues; 88% white; 37% non-religious).

Views of the technology

Next, the researchers held a range of ethical views of synthetic biology (Fig. 2). A large majority of both synthetic biologists and ELSI researchers believed synthetic biology is morally acceptable (84%). A substantial portion, however, also agreed or were ambivalent (neither agree nor disagree) on whether synthetic biology could give humans too much power (28%) or allow people to "play god" (26%), a phrase that reflects concerns of power or the potential for hubris. Concerns with giving humans too much power or allowing people to "play god" are commonly associated with emerging technologies, such as synthetic biology, that involve the manipulation of genetic material (Dragojlovic and Einsiedel 2013a, NASEM 2017). Specific to synthetic biology, these concerns (along with other ethical and moral concerns) have been raised in both

the public (Dragojlovic and Einsiedel 2013b, Hart Research Associates 2013, Vandermoere et al. 2010) and academic realms (Dabrock 2009, Newson 2011). For our study, the range of answers researchers reported may reflect opportunities for recognition of the complexities of the issue, especially as potential ethical and moral areas of tension have been discussed within the scientific community (e.g., Cho and Relman 2010, Newson 2011, Torgersen and Hampel 2012). In short, our findings may represent either the outcome of or the potential for such discussions.

Perhaps unsurprisingly, the two groups of researchers did hold different views of the moral and ethical aspects of synthetic biology. In presenting these results, our intention is not to provide a definitive comparison of the researchers, but rather to indicate areas of potential differences that may represent professional differences and play a role in future public engagement. That said, more ELSI researchers reported a belief that synthetic biology "messes with nature" ($t = 2.36$, $p = 0.021$), a view that has been tied to religiosity with members of the public (Dragojlovic and Einsiedel 2013b). As such, a possible explanation for this difference in views is that, on average, ELSI researchers ($M = 4.48$, $SD = 3.63$) were more religious than the synthetic biologists ($M = 3.32$, $SD = 3.24$; $t = 2.51$, $p = 0.012$). Previous research on the moral and ethical concerns of synthetic biologists suggests another tentative explanation: synthetic biologists might disassociate the research itself from concerns of messing with nature, but not the potential applications (Ganguli-Mitra et al. 2009). In this view, synthetic biology is seen as part of the process of "escaping the natural [which] is part of what man does" (Ganguli-Mitra et al. 2009), or as a continuation of what scientific research has historically done. It might also be that some respondents interpret "messes with nature" as holding a negative connotation, and therefore as imbued with ethical or moral implications, and others view it simply as a statement of fact, as synthetic biology does involve changing nature.

The role of values in shaping views of morality and regulations

While the research does not capture what interpretation researchers bring for this view of synthetic biology "messing with nature," our analyses do dig deeper into how religiosity and political ideology could help explain differences in the moral and regulatory views of the researchers (Table 1). As seen in Fig. 3, the researchers overall found existing regulations for synthetic biology research sufficient, but not those concerning applications. Synthetic biologists appear to be more likely to agree that regulations for research and applications are sufficient (research: $M = 3.34$, $SD = 0.84$; applications: $M = 2.98$, $SD = 0.87$), compared to ELSI researchers (research: $M = 2.93$, $SD = 1.18$; applications: $M = 2.47$, $SD = 1.10$), but also more likely to express ambivalence, neither disagreeing nor agreeing that existing regulation is sufficient (research: $t = -2.58$, $p = 0.012$; applications: $t = -3.37$, $p = 0.001$). Meanwhile, ELSI researchers are more likely to not see regulations of both research and applications as sufficient and are more likely to express certainty in either agreement or disagreement. As mentioned above, the larger numbers of researchers who disagree that regulations of synthetic biology applications are sufficient compared to research regulations is in line with previous research where synthetic biologists expressed more concerns about the ELSI of potential applications, rather than the research itself (Ganguli-Mitra et al. 2009). Keeping in mind the differences arising based on the use (research or application) of the technology, we next focus on the role of values.

Our findings suggest that researchers' views on moral and regulatory considerations are shaped, to a degree, by researchers' religiosity and political ideology – but in different ways that depend on the researchers' area of work. Political ideology and religiosity impacted synthetic biologists' views on the overall moral acceptability of synthetic biology, even after controlling

for demographic traits and judgments of the risks and benefits of the technology. Although risk and benefit judgements had a large impact on both synthetic biologists' and ELSI researchers' perceptions of the moral acceptability of synthetic biology, synthetic biologists were also influenced by their religious and political views. Religious and conservative synthetic biologists were more likely to view synthetic biology as less morally acceptable. This finding is in line with past research on nanoscientists (Corley et al. 2009). Even as scientists are viewed as unbiased assessors of their work, they often still utilize the same cognitive shortcuts as members of the general public when understanding the societal or ethical implications of their work (Ho et al. 2011). As this finding concerns a moral question, not a strictly scientific one, it is understandable that scientists would rely on these perceptual filters to establish their beliefs. Why political ideology and religiosity do not predict ELSI researchers' perceptions is less clear. It could be that ELSI researchers, who consider the moral and ethical aspects of the science as part of their research, rely less on these cognitive shortcuts because such considerations are viewed as more professional than personal judgments. They might also share a common work experience and knowledge that makes their views on moral and ethical issues more similar to each other, regardless of their religiosity of political ideology.

On the other hand, however, views of the regulation of synthetic biology research and applications suggest that ideology and religiosity more strongly predict ELSI researchers' views than they do synthetic biologists'. Neither political ideology nor religiosity significantly predict synthetic biologists' views of regulations for either research or applications, but, interestingly, they do predict the views of ELSI researchers. Conservative ELSI researchers are more likely to think that existing regulations for both applications and research are sufficient. In this case, although political ideology and religiosity play a role of moral views, synthetic biologists might

not be influenced by these same heuristics with respect to regulations as they work intimately with research and applications on a day-to-day basis. This means they could be more professionally and financially invested in the continuation of synthetic biology research – a personal connection that could override ideological concerns or processing (Kahan et al. 2011). In sum, the results suggest that synthetic biologists and ELSI researchers may rely on values to form opinions about aspects of the technology that are more removed from their everyday professional capacity (i.e., synthetic biologists and morality; ELSI and applications and research), although these divisions are likely not clean-cut (e.g., some ELSI researchers work with regulations).

An open science? Participation in public engagement

Finally, we discuss synthetic biology researchers' involvement in public engagement. Overall, the researchers indicated they were involved in public outreach. Almost 90 percent of synthetic biologists reported either frequently (20%) or infrequently (67%) engaging in public outreach efforts related to their work, with just 13 percent never engaging.[2] ELSI researchers, however, reported significantly more frequent engagement ($t = 4.75$, $p < 0.01$). For ELSI researchers, the number of those frequently engaging climbed to 44 percent, with almost half (49%) reporting they participated in engagement activities infrequently and only 7 percent reporting that they never engage (Fig. 1).

The researchers indicated they talked with reporters about their work to a lesser extent. Most respondents infrequently spoke with reporters about their research (synthetic biologists: 67%; ELSI researchers: 63%). Following a similar pattern as the responses on public engagement, ELSI researchers spoke with reporters significantly more frequently than did their

[2] The 'Infrequently' category included those who indicated they participated 'Less than once per year' or 'A few times a year,' while the 'Frequently' category included 'Every few months to once a month' and 'A few times a month.

synthetic biologist counterparts ($t = 4.85$, $p < 0.01$). As previous research suggests that most interactions with journalists stem from the reporter contacting the researcher (Allgaier et al. 2013), the lower rates of frequent scientist-reporter interactions could reflect researchers simply not being approached regularly. This might occur because of a lack of news interest or because of the inaccessibility of researchers to journalists, for example, due to working in industry or due to an absence of research coverage from their organization's public information office (Allgaier et al. 2013). Even with these potential impediments, well over half of the researchers have spoken with reporters.

The high number of researchers who report participating in public engagement activities or speaking with reporters, at least infrequently, is promising. Interestingly, previous research on the public engagement activities of university scientists has suggested that those in the biological fields were more likely to avoid outreach because of the potential for topic overlap with controversial societal issues (Johnson et al. 2013). Although we did not ask about the specific types of engagement activities researchers participated in (e.g., panel discussions, science cafés, hands-on activities geared toward children), the researchers' willingness to engage with the public indicates an openness toward communicating about their research and synthetic biology, and potentially about its social and ethical implications.

Conclusions

Our findings provide evidence that researchers' views of the moral and regulatory aspects of synthetic biology are not just a construct of their professional judgements but are filtered through belief systems, similar to what we see for non-expert audiences. After controlling for other factors, characteristics such as political ideology and levels of religiosity matter for

synthetic biologists with respect to the moral acceptability of synthetic biology. For views on regulation, however, synthetic biologists' views could be more closely linked to their own research and day-to-day experiences, which override ideological or religious processing for views on regulation more so than they do with respect to the moral aspects of the technology. For ELSI researchers working with synthetic biology, we see opposite effects with the issue of regulation appearing to be at least partially a political one, while moral considerations do not differ by religiosity or political ideology within this group. Although the concept that experts do not simply rely on impartial judgments to form opinions about their area of expertise is not new (e.g., Corley et al. 2009, Ho et al. 2011, Jasanoff 1990b), this finding applied to synthetic biology researchers has important implications for the policy decisions and public opinion formation about the science. These results also provide further support for the need for decisions about science to move beyond self-regulation and into public discourse, an idea that is supported by those within the field (Ganguli-Mitra et al. 2009). It also highlights, however, that although researchers share many traits and experiences, they are not a purely homogenous group in terms of values and opinions of the field. Given the differences we found between researchers depending on the work they do with relation to synthetic biology and their own value-based characteristics, researchers hold a range and nuanced mix of views and levels of concern for the moral, social, and political considerations of synthetic biology. The number of researchers already engaged in public outreach suggests opportunities for discourse between the range of expert and public experiences and views.

As choices concerning the regulation of synthetic biology arise along with other emerging genetic technologies, public views of the field and the involvement of researchers connected to the field can greatly impact the future of the technology, especially as both groups

continue to participate in workshops and meetings that focus on the sociopolitical considerations of synthetic biology. That the majority of researchers already engage with the public is an encouraging starting point. By approaching outreach activities on synthetic biology with an awareness of the factors that influence their own views, synthetic biologics can continue to engage more fully and openly with members of the public, even as decisions on the regulatory, technological, and ELSI aspects of synthetic biology become more imperative.

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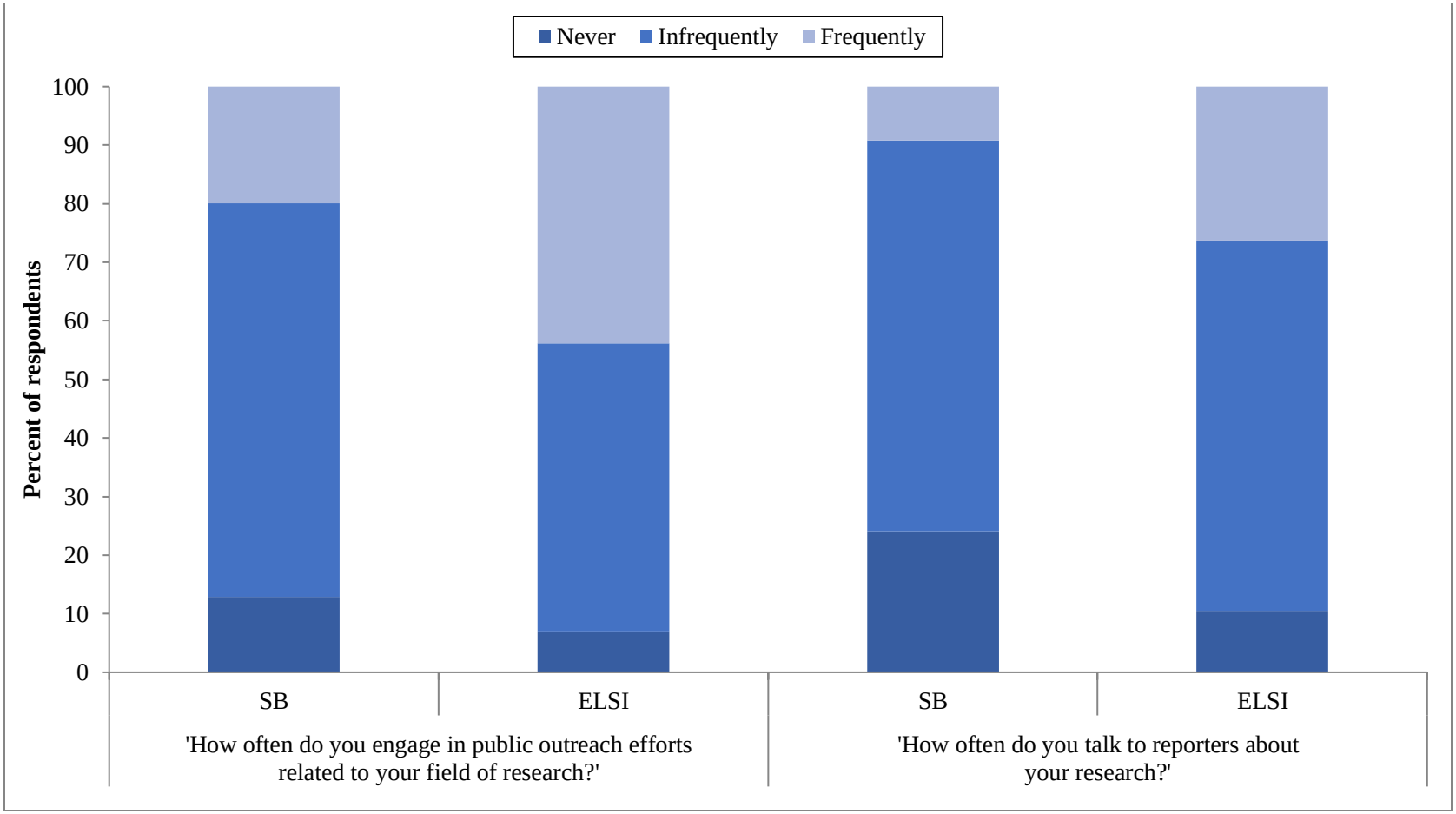

Figure 1. Involvement in public engagement and outreach efforts. Percentage of synthetic biologists (SB; N=732) and ELSI researchers (ELSI; N=57) who report engaging in public outreach efforts or talking to reporters. Most respondents participated in public engagement either frequently or infrequently, with only a minority reporting never doing so. ELSI researchers engaged more frequently than did synthetic biologists. The 'Infrequently' category included those who indicated they participated 'Less than once per year' or 'A few times a year,' while the 'Frequently' category included 'Every few months to once a month' and 'A few times a month.'

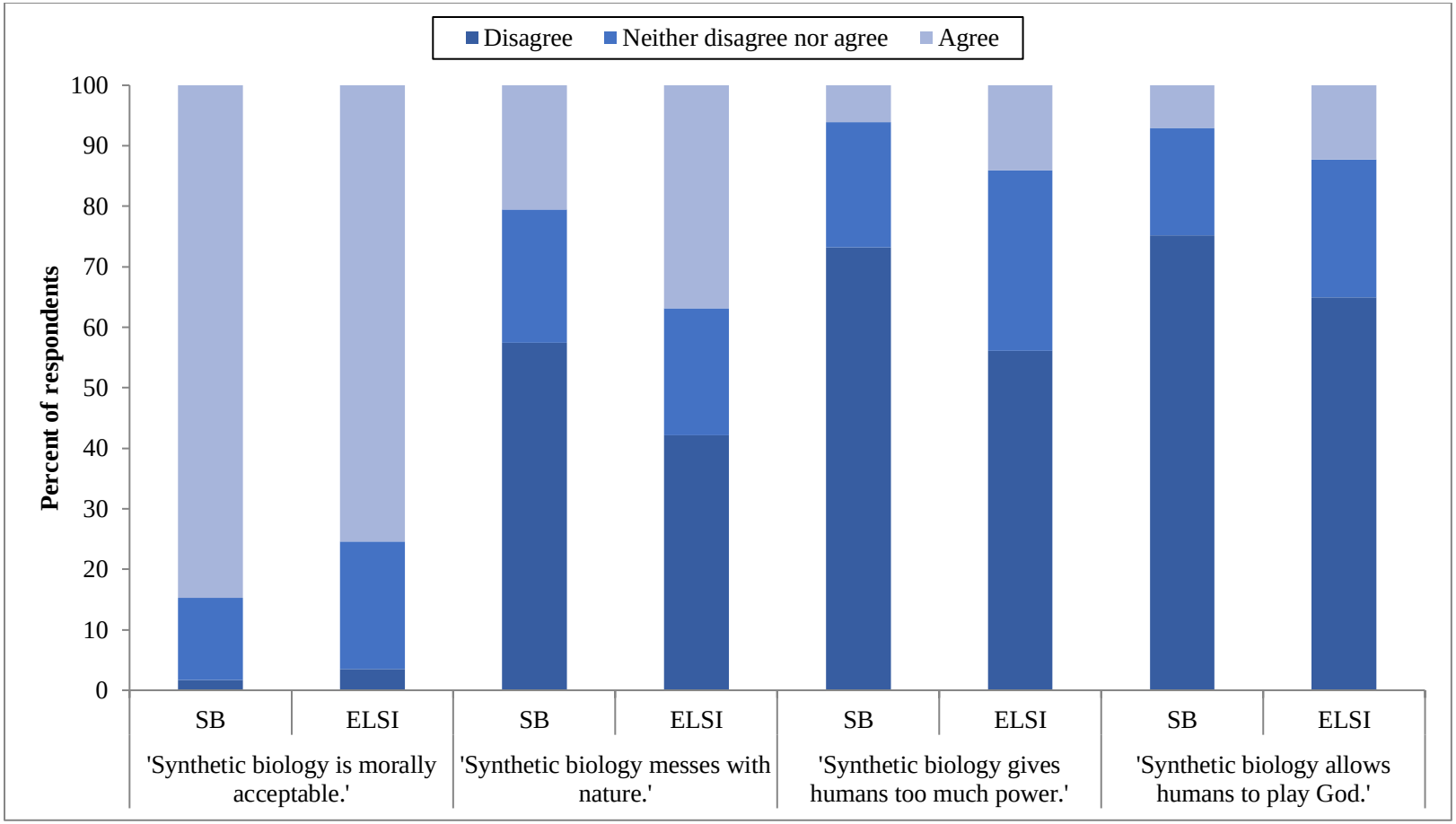

Figure 2. Attitudes toward the moral and ethical considerations of synthetic biology. Percentage of synthetic biologists (SB; N=722) and ELSI researchers (ELSI; N=57) who agree or disagree with four statements about the moral and ethical implications of synthetic biology. Most respondents agree that synthetic biology is morally acceptable. The majority disagree with statements about synthetic biology giving humans too much power and allowing them to play God. Reactions to the statement on synthetic biology messing with nature were more mixed. A considerable portion of respondents neither agreed nor disagreed for each of the statements. The 'Disagree' category included 'Strongly disagree' and 'Disagree' responses, and the 'Agree' category included 'Strongly agree' and 'Agree.'

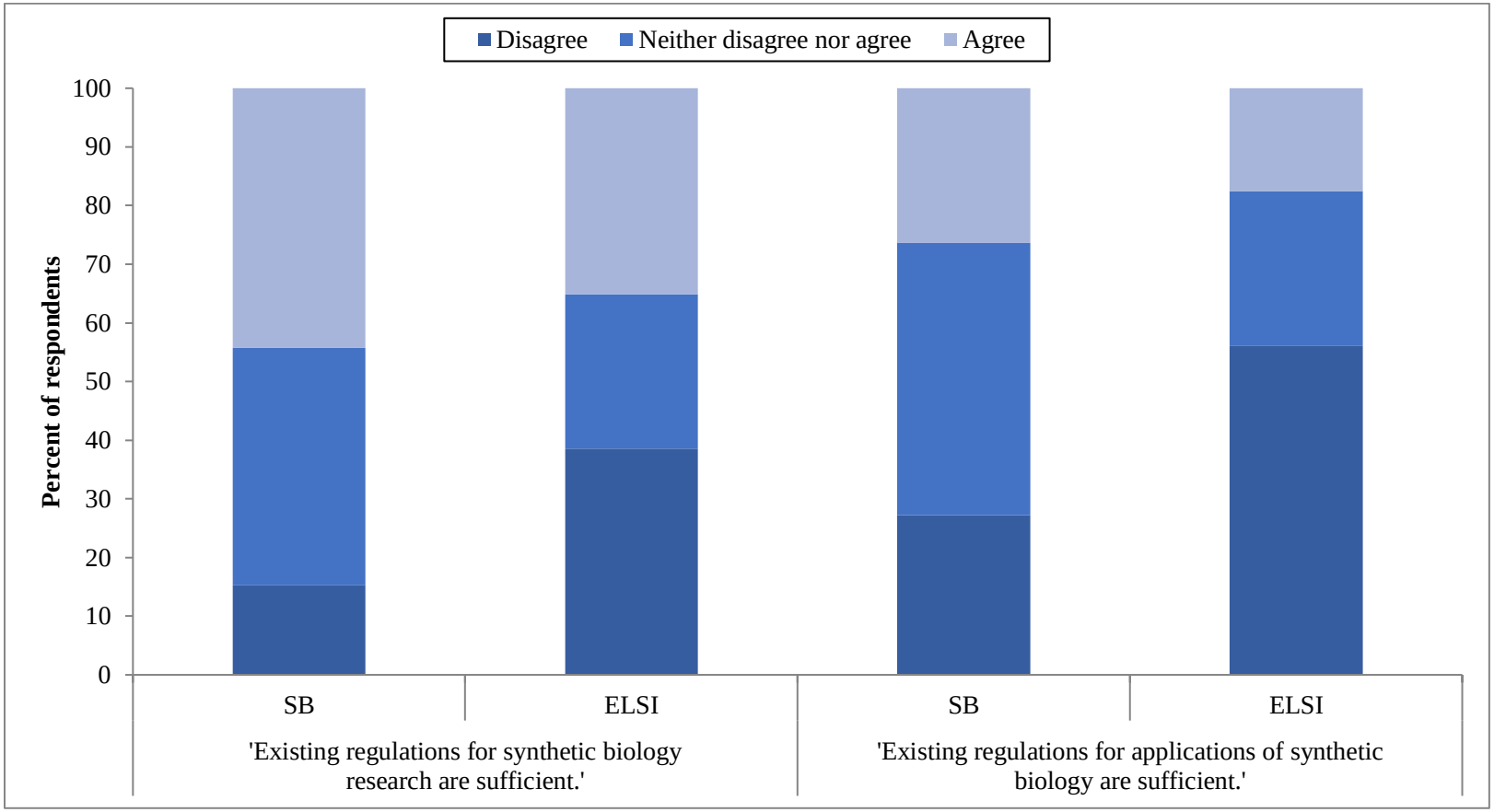

Figure 3. Views on regulations. Percentage of synthetic biologists (SB; N=722) and ELSI researchers (ELSI; N=57) who agree or disagree with two statements about the sufficiency of synthetic biology regulations with respect to research or applications. The researchers were generally more accepting of the existing regulations for research, but were more skeptical of the existing regulations concerning applications. More synthetic biologists agreed that regulations for both research and applications are sufficient, while more ELSI researchers saw regulations of both research and applications as insufficient. A considerable portion of both sets of researchers reported ambiguity in the sufficiency of current regulations. The 'Disagree' category included 'Strongly disagree' and 'Disagree' responses, and the 'Agree' category included 'Strongly agree' and 'Agree.'

Table 1. OLS regression predicting the moral acceptability of synthetic biology and views on its regulation, for both synthetic biologists and ELSI researchers.

	Synthetic biology is morally acceptable.		**Existing regulations for synthetic biology research are sufficient.**		**Existing regulations for applications of synthetic biology are sufficient.**	
	Synthetic biologists	*ELSI researchers*	*Synthetic biologists*	*ELSI researchers*	*Synthetic biologists*	*ELSI researchers*
Block 1: Demographics						
Gender (male=0)	-0.06	-0.05	-0.03	0.31*	-0.04	-0.04
Academic Age	-0.03	0.02	-0.02	0.15	0.04	0.18
Incremental R^2	**0.6%**	**0.9%**	**0.1%**	**7.4%**	**0.3%**	**3.6%**
Block 2: Professional judgements						
Benefit perceptions	0.33***	0.38*	0.08*	0.19	0.02	0.11
Risk perceptions	-0.18***	-0.25†	-0.22***	-0.26†	-0.30***	-0.36*
Incremental R^2	**18.6%*** **	**20.6%** **	**6.7%*** **	**13.2%***	**9.0%*** **	**18.8%***
Block 3: Heuristics						
Religiosity	-0.11**	-0.21	-0.04	-0.21	-0.01	-0.19
Political ideology (liberal=low)	-0.12***	-0.10	-0.01	0.36*	0.04	0.39**
Incremental R^2	**3.5%*** **	**6.8%**	**0.2%**	**10.6%†**	**0.1%**	**12.2%***
Total R^2	**22.8%*** **	**28.3%***	**7.0%*** **	**31.2%***	**9.4%*** **	**34.6%** **

*Note: The three dependent variables, plus benefit and risk perceptions, are on a 5-point scale (1 = 'Strongly disagree,' 5 = 'Strongly agree'). Synthetic biologists: N=732; ELSI researchers: N=57. †p<0.1 (for ELSI researchers only); *p<.05; **p<.01; ***p<.001*