Mapping the Integrative Field: Taking Stock of Socio-Technical Collaborations

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Abstract
Responsible innovation requires that scientific and other expert practices be responsive to society. We take stock of a variety of collaborative approaches to *socio-technical integration* that seek to broaden the societal contexts technical experts take into account during their routine activities. Part of a larger family of engaged scholarship that includes inter- and trans-disciplinarity as well as stakeholder and public engagement, we distinguish collaborative socio-technical integration in terms of its proximity to and transformation of expert practices. We survey a variety of approaches that differ widely in terms of their integrative methods, conceptions of societal context, roles, and aspirations for intervention. Taking a handful of "communities of integration" as exemplars, we then provide a framework for comparing the *forms*, *means*, and *ends* of collaborative integration. We conclude by reflecting on some of the main features of, and tensions within, this developing arena of practical inquiry and engagement and what this suggests for integrative efforts aimed at responsible innovation.

Keywords: Socio-technical Integration; Collaboration; Transdisciplinarity; Public Engagement; Technology Assessment;

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1. Introduction

Throughout Europe, North America, Australasia, and elsewhere, the integration of social, ethical, cultural, environmental and other "societal" considerations into scientific and technical practices has been a noticeable theme within recent research and development policy mandates (Fisher & Rip, 2013; Macnaghten et al., 2005), programs (Owen, 2014; Rodriguez et al., 2013), and program planning (Ommer et al., 2011; Fisher, 2014). Departing from past policies for societal research *on* science, these policies suggest more collaborative models of societal research *with* science. Meanwhile, practical scholarly engagement with expert and technical practices is itself framed in terms of collaborating with and directly influencing these same practices. We take stock of this emerging field of engaged scholarly collaborations aimed at *socio-technical integration*, develop a framework for comparing integrative methods and goals, and reflect on the results in light of responsible innovation.

Although socio-technical integration can take many forms, it is generally characterised by the reciprocal and productive combination of opposing, diverging, or previously segregated contextual dimensions of expert practices in the pursuit of consequential, often policy-relevant, ends. It is part of a larger family of participatory research approaches that includes scholarly engagement (Felt, 2014; Hackett & Rhoten, 2011), ethical, legal, and social implications/aspects (ELSI/ELSA) research (Juengst, 1991), laboratory studies (Hess, 2001), team science (Stokols et al, 2008), applied ethics (van Gorp, 2005), technology assessment (Van Eijndhoven, 1997; Guston & Sarewitz, 2002), inter- and transdisciplinarity (Bergmann et al., 2012; Frodeman et al., 2010; Wickson et al., 2006), and public engagement (Macnaghten et al., 2005; Wynne, 2011), among others. Like many of these, engagements aimed at socio-technical integration tend to confront challenges arising from differences in language, practice, values, power and other potential sources of "incommensurability," "incongruence" or "discordancy" (Eigenbrode et al. 2007; McCormick et al., 2012; Sievanen et al. 2011; Bracken & Oughton 2006; Rabinow et al., 2009). As we define it, however, collaborative socio-technical integration is distinct from these related approaches primarily insofar as it involves close, transformational interaction with scientific and technical experts.

Such collaborative integration appears as a central component of visions for "responsible (research and) innovation" (Guston et al., 2014; Owen et al., 2012; von Schomberg, 2013), "anticipatory governance" (Barben et al., 2008), "reflexive governance" (Voss et al., 2006), and the notion of "convergence work" (Stegmaier, 2009). These visions concern the explicit integration of societal considerations into scientific and technical practices as knowledge systems and technological trajectories evolve, and they have precedents in earlier calls (Bronk, 1975; Mitcham, 1994; van Eijndhoven, 2000), programs (Hollander & Steneck, 1990; Juengst, 1991), methods (Friedman, 1996; Schot & Rip, 1997) and frameworks (Williams & Edge, 1996). The reinvigoration of established approaches and the proliferation of more recent ones, however, provides an opportunity to take stock of the collaborative pathways to integration. Accordingly, we outline the main features of collaborative socio-technical integration in terms of its multi-dimensional interactions with expertise. We then take as exemplars a number of "communities of integration" to illustrate a conceptual framework that facilitates comparison while capturing a diversity of relational (*forms*), methodological (*means*), and normative (*ends*) orientations found within this integrative field. The paper concludes by offering reflections on synergies, tensions, and future research directions in relation to responsible innovation.[8]

2. Overview of the Field

Collaborative socio-technical integration is the subject of explicit or implicit treatment in a wide range of literature, including case studies (Ribes & Baker, 2007), projects (Nydal et al., 2012), reports (Paletz et al., 2010), handbooks (Bijker & d'Andrea, 2009), and manifestos (Balmer et al., 2012). Also discernable is a handful of sustained or coordinated programs that have given rise to several communities of practice for socio-technical integration (e.g., Cho et al., 2008; Fisher & Schuurbiers, 2013; Friedman et al., 2013; Goorden et al., 2008; Rip & van Lente, 2013). Although few comparisons of integrative roles and programs have been attempted (Boenink, 2013; Calvert and Martin, 2009; Rabinow and Stavrianakis, 2013), a number of recent edited collections provide contours of the field. Some of these collections are organized around particular theoretical frameworks (Gorman, 2010; Plaisance & Fehr, 2010); others assemble various methodological approaches (O'Rourke et al. 2013), sometimes focusing on the laboratory as the site of integration (Doorn et al., 2013; van der Burg et al., 2013); while others emphasize normative aspects of integration (van der Poel and Verbeek, 2006; Zuiderent-Jerak, 2007) or its relation to policy and governance (Levidow and Neubauer, 2014; Fisher, 2011; Stegmaier, 2009).

Delineating Socio-Technical Integration

Rodriguez et al. (2013) define socio-technical integration as "the explicit incorporation of activities devoted to broadening the social and ethical aspects that are taken into account during core scientific and engineering research and development (R&D) activities in such a way as to shape R&D pathways in socially desirable ways" (Rodriguez et al., 2013: 1126). Fisher and Maricle (2014) define it as "any process by which technical experts account for the societal dimensions of their work as an integral part of this work" (Fisher and Maricle, 2014). Notably, these definitions leave open the question of whether integration is accomplished by technical experts on their own or whether it takes the form of trans-disciplinary and/or cross-sector engagements involving others. On the other hand, Guston's definition includes the humanities and social sciences: "*Integration* is the creation of opportunities, in both research and training, for substantive interchange across the 'two cultures' divide that is aimed at long-term reflective capacity building" (Guston, 2014). We preserve this meaningful distinction between integration as an activity proper to technical expertise and integration as an essentially cross-cultural endeavour by focusing on the idea of *collaborative socio-technical integration*, which we conceptualize in terms of three key characteristics: As we explain next, collaborative socio-technical integration focuses on relations of expert practices to their (often segregated) societal context, operates in close

[8] The present paper is an outgrowth of, and to some extent a reflection of, the recently formed Communities of Integration Network (COIN), which has held meetings at Arizona State University (May, 2013) and Waterloo University (June, 2014). The paper is based on ideas initially conceived in a project proposal (Fisher, Seager, Gorman, O'Rourke, and Julie T. Klein).

proximity to the expert practices in question, and functions to catalyse or support transformation of those practices in their societal context.

Accounting for Context. As noted, the literature emphasizes bridging segregated or diverging categories, with 'technical' denoting some form of specialized expertise and 'societal' denoting important contextual dimensions of expertise that are either overlooked or neglected. Depending on the particular approach and the participating experts, the societal context can encompass cultural, ethical, political, environmental, linguistic, epistemological, axiological, and numerous other value dimensions. Collaborative integration seeks to work deliberatively, explicitly, and reflectively across variously conceived and constructed "socio-technical divides." These include expert and lay ways of knowing (Stokols et al. 2003, Pohl & Hirsch Hadorn 2007), disciplinary distinctions between social and technical actors (Gregory et al. 2012), divergences between human value dimensions and technical rationalities (Lempert et al. 2006, Schön, 1983), and intersections between science and policy/politics (Lempert et al. 2003, Pielke, 2007). Explanations for why these divides and limitations exist in the first place vary, but they tend to make reference to the nature and acquisition of expertise itself.

Close Proximity. This emphasis on the contextual limitations of expertise implies a role—or rather roles—for others. Just as integration approaches tend to share an analytical distinction between societal and technical categories, so also do they tend to relate these categories through the work of intervention-oriented integration agents. While integration approaches differ in how they represent the roles of these would-be collaborators, they all tend to calibrate their interventions to the everyday practices, judgments, and experiences of the experts in question. Some see expertise as lacking a particular embodiment of ethics or values and emphasize the introduction of and sometimes advocacy for new content or capacities (Rabinow, 2009; Boenink, 2013; Shilton, 2013). These approaches often portray the integration agent as an expert or representative who speaks with authority. Others see socio-technical divides as co-produced (Jasanoff, 2004) and emphasize social, moral, or epistemological reflexive awareness of the focal experts (Doubleday, 2007; Eigenbrode et al. 2007; Fisher & Miller, 2009; O'Rourke & Crowley 2013; Tuma, 2013). These approaches tend to emphasize the mutual learning that occurs on both sides of the collaboration and that enables the integration agent to articulate contextually-specific questions, reflections, and insights. In all cases, integration approaches seek to situate themselves closely alongside of and within the practice of technical expertise, moving in the same cultural, linguistic, and conceptual spaces and operating with "adjacency" (Rabinow and Bennett, 2012) and "proximity" (Guston, 2014) and doing so "midstream" (Fisher et al., 2006).

Practical Transformation. Finally, collaborative integration emphasizes influencing and affecting change in how expert practitioners identify and engage their societal contexts (Calvert, 2013; Darling et al., 2014; Fisher, 2007; Flipse et al., 2013; Krabbenborg, 2013; Schuurbiers, 2011; Shilton, 2013; Taebi et al., 2014;

Valve & McNally, 2013; Wickson et al., 2006). Successful collaborative integration inflects one or more integral components of the engaged expert practices, whether by effecting new "inputs" to them (Barben et al., 2008; Cho et al., 2008) or through their "modulation" (Fisher et al., 2006; Rip, 2002). Thus, a crucial difference between collaborative socio-technical integration and other forms of multi-disciplinary research is that the interactions include an explicit recognition by the domain experts of the societal contexts in which their work is conducted and in which it will be applied (Rodriguez et al., 2013; Schuurbiers & Fisher, 2009; Shilton, 2013). Successful integration demonstrably *changes* technical practice, modifying it both formally and tacitly (Fisher & Maricle, 2014).

These three characteristics of collaborative approaches to socio-technical integration are consonant with position, long maintained by the field of Science and Technology Studies (STS) that, while experts are "indispensible to the politics of knowledge societies" (Jasanoff, 2005), they are nevertheless not the only ones "competent to make decisions about science and its trajectory" (Kleinman, 1989). Here, we treat expertise as something that is acquired by individuals and social groups through various processes of socialization and that is embodied in specific sets of cultural practices. Accordingly, the collaborative engagement of expert practices tend to see expertise as fundamentally limited in important ways due to the its specialized focus, but calls for integration differ in regards to how this limitation is constituted and how it ought to be addressed.

Calls for Socio-Technical Integration

Even with the restrictions imposed by these three characteristics, contemporary calls for socio-technical integration are diverse in terms of their source and scope. Some highlight scientific agency and emphasize "collaborative" (Calvert, 2013; O'Rourke & Crowley, 2013; Rabinow & Bennett, 2009a) and "embedded" (Felt, 2014; Fisher, 2006) interactions with humanities scholars and social scientists. Others emphasize the need for deliberation among scientific experts, either with citizens and stakeholders (Funtowicz & Ravetz, 1993, 2001; Kleinman, 2000; Scolve, 1995) or with a specific focus on developing the reflexive capacities of scientists (Mejlgaard et al., 2012; Gibbons et al., 2004). Of course, these two areas of emphasis can overlap (Barben et al., 2008; Macnaghten et al., 2005). Calls for integration can resemble calls for building capacities such as effective communication within scientific teams (NAS 2004; 2005)[9] or responsiveness of techno-scientific programs to public values (Fisher et al., 2006; Stilgoe et al., 2013; Taebi et al., 2014). It should also be noted that while some calls target applied science and engineering design, in order to shape technological and innovation outcomes, others emphasize the importance of engaging the reflexive capacities of expert practitioners themselves, including within socialization and training sites such as laboratories that are focused solely on basic or fundamental science (Gjefsen & Fisher, 2014).

[9] For instance, the National Academy of Science (NAS 2005: 81) recommends that "Researchers ... desiring to work on interdisciplinary research, education, and training projects should immerse themselves in the languages, cultures, and knowledge of their collaborators."

A groundswell of science and technology policies throughout the industrialized world, including high-level prescriptions in the United States and Europe, have recently mandated socio-technical integration in an attempt to address societal concerns associated with public investments in science and innovation (Fisher, 2011; Macnaghten et al., 2005; Rodriguez et al., 2013). This shift in policy rhetoric has been accompanied by a shift in program funding that moves away from the parallel research exemplified by the ELSI program of the Human Genome Project toward a more integrated approach that attempts to bring ELSI research to bear on technical practice (Fisher, 2005; cf. Balmer and Bulpin, 2013; McCain, 2002; Rabinow & Bennett, 2009b; Rodriguez et al., 2013).

This purported shift toward integration is conspicuous in the U.S. National Nanotechnology Initiative's requirement for "integrating research on societal, ethical, and environmental concerns with nanotechnology research and development" (US Congress, 2003; cf. Bennett & Sarewitz, 2006; Fisher & Mahajan, 2006). This law led to the explicit incorporation of societal research into nanotechnology network and center training programs (Patra, 2011; McGuire & Visneu, 2012) and into laboratory research (Fisher, 2007; Tuma, 2013); it also authorized the funding of two large societal research centers, one of which explicitly adopted socio-technical integration as part of its strategic vision (Guston, 2014). European policy prescriptions for the "harmonious societal integration of new scientific and technological knowledge" (European Commission, 2007) ostensibly extend integration to a wider range of research and closely involve the social sciences in numerous ways (Hackett 2014). Indeed, references to socio-technical integration within formal European solicitations have increased in both absolute and relative numbers over a recent twelve-year period, with social scientific and humanistic research increasingly operating as integral components of core science and engineering activities (Rodriguez et al., 2013). Alongside the US and Europe, comparable policies have also been issued in the UK, Canada, Norway, Belgium, and Netherlands, and have been proposed for a variety of technological areas, including genetics, synthetic biology, neurotechnology, converging technologies, and geo-engineering (Bioethics Commission, 2014; Fisher and Rip, 2013; Ommer et al., 2011; Owen, 2014; Roco et al., 2013).

Justifications for engaging expertise in an integrative manner can echo those for technology assessment, such as working towards "better technology in a better society" (Schot and Rip, 1997) or "enhancing linkages between innovation and societal action in ways that can add to the value and capability of each" (Guston and Sarewitz, 2002). Often, calls for expert engagement represent science and technology as always inflected by a particular set of social interests, values, and assumptions (cf. Bijker, 1995), arguing that these values are typically those of elite social groups (Irwin, 1995) or are shaped by cultural and institutional arrangements that are taken for granted (Fountain, 2004; Jasanoff, 2005). In these cases, various explicit themes emerge, such as power (Stirling, 2008; van Oudheusden, 2014), ethics (Boenink 2013; Khushf, 2007; Rabinow and Bennett, 2009b), social justice (Fehr, 2011), environmental sustainability (Voss et al., 2006; Sweet et al., 2014; Wiek et al. 2014) and democratic values (Guston, 2014; Macnaghten et al., 2005).

As stated, despite the diversity of values that motivate calls for integration, most implicitly or explicitly acknowledge limits of specialization. Thus, technical expertise comes across as bounded in one way or another by its specialist focus. To make up for its limitations, expert practices either require additional specialist expertise or broader awareness of contextual complexity. In both cases, calls for integration suggest that the power of the technical gaze to frame problem and solution spaces simultaneously gives rise to blind spots that can reduce, even undermine, its legitimacy and effectiveness. Responding to these blind spots requires either building the reflexive capacity or supplementing the disciplinary capacity of expert practitioners. Calls for enhancing reflexive capacity—or the reflexivity rationale—seek to productively alter, even disrupt, scientific practices from within by introducing new contextual elements or awareness (Fisher et al., 2006; Wynne, 2011). For example, in responsible innovation, socio-technical integration is seen as a mechanism for embedding societal reflection within existing research and innovation processes (Owen et al., 2012). Likewise, in anticipatory governance, integration is aimed at "long-term reflective capacity building" (Guston, 2014). By contrast, calls for supplementing disciplinary capacity—or the interdisciplinary rationale—seek to support existing practices by helping scientific and other expert teams achieve their own stated goals. These calls tend to focus more on aptitudes thought to be relevant for effecting socio-technical integration, including studies of collaborative practice (Salazar et al. 2011), interdisciplinary team facilitation (Morse et al. 2007, Salazar et al. 2012), and effective technical communication (O'Rourke et al. 2013).

Theoretical Developments

Socio-technical integration calls and approaches are sympathetic to constructivist epistemology and to work within the field of STS more generally. Thus, many are concerned with the nature and distribution of expertise; the distance between expertise and citizens; the problems that disciplinary paradigms create for conducting, applying, coordinating, and communicating research; and the problem of ensuring societal responsiveness and mutual assurance. In each case, the problem can be seen as one of recognizing that the social context of specialized knowledge-production both enables and constrains the life worlds of actors. In theorizing the interactions that collaborative integration creates, John Dewey's theory of inquiry is influential as are two more recent approaches within STS: Studies of Expertise and Experience (SEE) and Trading Zones.

Mutual learning is important in the case of reflexive integration approaches, which refer to theories of inquiry and learning both to describe and prescribe their practices. Several communities of integration draw explicitly upon Dewey (Fisher & Schuurbiers, 2013; Krabbenborg, 2013; Rabinow & Bennett, 2012) and on reflective learning more generally (van de Poel & Doorn, 2013). For instance, midstream modulation posits analytically distinct stages of human agency in relation to its social material interactions, emphasizing reflexive awareness as the focal point for intervention in decision processes (Fisher & Mahajan, 2010; Fisher et al., 2006). Here, collaborative humanistic and social science engagement can intensify the experience of what Dewey called a "problematic situation" by technical experts, triggering "inquiry" and "encouraging both first- and second-order reflective learning" (Schuurbiers, 2011; cf. Fisher and Schuurbiers, 2013).

Studies in Expertise and Experience (SEE) and Trading Zones highlight capabilities they deem essential for integration. In the case of SEE, Collins & Evans (2002, 2007) develop a typology of expert knowledge in which they make a distinction between 'contributory expertise' and 'interactional expertise'. Contributory expertise is acquired by successful socialization into a given community of practice, with contributory experts defined by the mastery of both the language and practice of that domain. Interactional expertise is also acquired by socialisation, but only in the language of the domain. The importance of this distinction for collaborative socio-technical integration is that it provides a way of understanding how different groups of experts can come to a shared understanding of each others' domains of practice without necessarily being able to perform each others' work (Collins et al. 2007; Plaisance & Kennedy, 2014; Gorman 2002; Selinger et al 2007). It explains, for example, how a social scientist or humanities scholar can understand the work of the researchers in the laboratory, how those researchers can understand the work of the other specialists, and how managers of large projects can interact successfully across a diverse range of expertises (Collins 2004, 2011; Collins & Sanders 2007; Selinger & Mix 2004). The current test for the acquisition of interactional expertise is through an "imitation game" that takes the form of a modified Turing Test in which an expert judge sets questions that are answered by another expert practitioner and the person be tested. By examining what judges ask, how different players respond to these questions, and how these answers are judged by contributory experts, it is possible to explore the content, level, and distribution of interactional expertise across social groups (Collins et al. 2006, Collins & Evans 2014; Evans & Crocker 2013). In general, players with higher levels of interactional expertise would be better able to contribute to socio-technical integration as they would be able to move more easily between the different expert communities.

Theoretical work around Trading Zones examines the shared arenas formed when individuals belonging to different fields with incommensurable languages and practices negotiate terms of exchange. Such exchanges are thought to be necessary when disciplinary cultures have to share knowledge, resources, and time to accomplish a goal such as inventing radar or new particle detectors (Galison 1997). Through in-depth cases studies, trading zones researchers illuminate how cultures, such as different academic or industrial disciplines, trade around a jointly created boundary system, with interactional expertise being one of several possibilities (Collins et al. 2007; Gorman 2002; Gorman, 2010). By examining how different kinds of collaboration succeed or fail, trading zones research can be used to overcome the incommensurability that impedes effective integration. It is important to note that not all kinds of trading zones can be classified as examples of collaborative socio-technical integration, nor are all forms of collaboration accurately described as trading zones.

Criticism

The justifications, practices, and outcomes of integration have their own sets of limitations to contend with. Above all, criticism of collaborative approaches to integration points to their potential loss of critical distance (Guston, 2014; Nordmann and Schwartz, 2010; Valve and McNally, 2013). Closely related to this are concerns over the capture of social science and humanities scholars and their loss of agency (Doubleday and Visneu, 2010; Felt, 2014; Jasanoff, 2011; Rodriguez et al., 2013). For instance, Valve and McNally suggest that collaborative relationships come with the cost of social scientific "loyalty" to the scientific or technological trajectories envisioned by experts. Integration can also run the risk of overlooking historical and theoretical perspectives (Jasanoff, 2011) and of failing to appreciate the already normative and reflexive dispositions of scientific experts (Caudill, 2009; Thoreau, 2011). Finally, there are scholars who question the outcomes of integration. Some find them forthcoming but limited to a narrow set of actors or sites (Krabbenborg, 2013; Wynne, 2011); others find few or no pertinent integration outcomes (Rip, 2009; et al., 2014)[10]; and still others find that established power dynamics and asymmetries preclude or undermine meaningful integration in the first place (Doubleday and Visneu, 2010; Rabinow and Stavrianakis, 2013; van Oudheusden, 2014).

3. Communities of Integration

In this section, we highlight the practice of collaborative socio-technical integration by focusing on four communities of practice chosen to illustrate the different dimensions of the framework we propose: Human Practices, Socio-Technical Integration Research (STIR), the Toolbox Project, and Value Sensitive Design (VSD). We briefly describe each community in terms of their contextual and collaborative stance (*forms*), main methods (*means*) and motivating rationales (*ends*), summarizing these descriptions in Table 1.[11]

- *Human Practices* pursues collaboration – including the mutual definition and adaptation of problems, modes of inquiry, and problem solving approaches – among anthropologists, biologists, and ethicists midstream during innovation processes; as such, it is a "post-ELSI" approach that moves beyond downstream societal implications, documenting the "ramifications of research as they unfold" (Rabinow & Bennett 2009b). Human Practices "poses and reposes" (*ibid.*) questions of how natural scientific research is ramifying and contributing to the development of the near future, often by resorting to "frank speech" (Rabinow & Bennett, 2012). As an intervention, it designs and sustains interactions between multiple disciplines that consider the possible futures enabled by contemporary equipment (such as emergence and remediation) and their consequences for the metric of collaboration, mutual flourishing. Application and development of the approach has primarily

[10] Even in the case of demonstrable outcomes, critics would still be right to question whether the outcomes are worth the effort, especially considering that integration can require a significant investment of time on the part of both the integration agent and the collaborating experts. See work by the STIR project (e.g., Fisher 2007 and Flipse et al. 2013), which attempts to establish an empirical basis for considering this potential criticism.

[11] The landscape of approaches to collaborative socio-technical integration is broad and diverse. There are a number of additional scholarly communities that include diverse methodological approaches to socio-technical integration in their research purview, including but not limited to science of team science (Falk-Krzesinski et al. 2011), constructive technology assessment (Schot and Rip, 1997), ethics consultation (Fletcher and Siegler 1996; Cho et al., 2008), integration and implementation sciences (Bammer, 2013), socially relevant philosophy of/in science and engineering (SRPOISE; Fehr and Plaisance, 2010), and field philosophy (Frodeman, 2010).

taken place in and around two synthetic biology laboratories (Rabinow and Stavrianakis, 2013).

- *Socio-Technical Integration Research (STIR)* is a platform for situated and ongoing dialogue between an "embedded humanist" and scientific experts. Aimed at midstream modulation, dialogue is guided by a "decision protocol" (Fisher, 2007) and ideally moves from shared descriptions of social processes to collaborative inquiry. STIR seeks to probe the societal responsiveness of expert practices through productively disrupting their routines and expectations. STIR "laboratory engagement studies" conducted in university and industrial labs across a dozen nations correlate these probing activities to the transformations of scientific practices by practitioners themselves (Fisher, 2007; Fisher and Schuurbiers, 2013; Fisher et al., 2010; Flipse et al., 2013, 2014; Schuurbiers, 2011). Thus, as a research program, STIR 1.0 probes the conditions and capacities for broadening socio-technical integration while, as an intervention, STIR 2.0 attempts to exercise these capacities deliberatively and in light of multiple normative commitments (including ethical reflection, sustainability, and democratic governance).
- *The Toolbox Project* studies how epistemic reflection and sharing can encourage mutual consideration of underlying research assumptions and worldviews (Eigenbrode et al. 2007). The approach is based on the use of a modular survey instrument to structure dialogue among cross-disciplinary collaborators in a facilitated workshop. Each module opens with a "core question" that announces the focal issue of that module followed by several "probing statements" that highlight aspects of the focal issue. The workshop setting is designed to facilitate a structured dialogue in which participants articulate their own research worldviews and exchange disciplinary perspectives with one another. The goal is to increase self- and mutual understanding, inducing improved team cohesion and scientific communication. The project has conducted workshops in academic and non-academic contexts with various groups, including transdisciplinary teams involving stakeholders (Crowley et al. 2010; O'Rourke & Crowley 2013; and Looney et al. 2013).
- *Value Sensitive Design (VSD)* is "a theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive manner throughout the design process" (Friedman et al., 2013). VSD explicitly broadens the term 'value' beyond financial or efficiency values, engaging with those things that "people consider important in life" (Friedman et al., 2008). Three types of investigation are used to consider the values at hand: Conceptual investigation considers the values, stakeholders, trade-offs, and relative weightings of values involved, as well as key terms, definitions, and issues. Empirical investigation then examines differences between values articulated and demonstrated in practice. Finally, technical investigations examine the underlying systems and embedded values within those systems. These three modes of investigation are ideally used proactively to influence design of technology, iteratively explore a holistic set of values, and consider a wide range of stakeholders. VSD has been applied primarily in the context of computer and information technology.

4. Mapping the Integrative Field

Socio-technical integration involves a host of conceptual and normative issues. We attempt to map this diversity among approaches to socio-technical integration using the exemplars described above.[12] We start by considering each approach in terms of three characteristics: the *forms* of collaborative integration, meaning how the approach positions itself in relation to the expert practices it engages, its *means*, understood in terms of the nature of its own practice, and its *ends*, represented here by the goals and values that motivate the integration approach and justify its pursuit.[13] We then collapse these different features into two orthogonal dimensions – values and capacities – upon which each approach is positioned in order to illustrate and facilitate more general comparisons.

Forms

Integration can assume a variety of *forms*, depending on which ideas or explanatory frameworks are privileged and which participatory relations are put in play by a particular community of practice. Here, we take the form of an integration approach to be revealed by how it is related to its domain of inquiry along two dimensions: (1) how it conceptualizes the relationship between the societal contexts it focuses on and the practices it engages, and (2) how it organizes the relationship between its own practices and those it engages. With respect to the first, we ask to what extent the approach represents the societal dimensions as latent within and native to the engaged practices, in which case it presents itself as engaged in *clarifying* (STIR, Toolbox) already intertwined dimensions; and to what extent it represents them as absent or otherwise missing from the practices, in which case the approach may tend to present itself as *introducing* (Human Practices, VSD) something new. The second dimension concerns whether the approach is positioned as somehow *embedded* within the site of the focal practices (STIR, Human Practices, VSD) or whether it organizes its own separate venue or parallel process (Toolbox). Positionality also concerns whether an approach is *independent* of (STIR) or *dependent* upon (Toolbox, VSD, Human Practices) the focal experts in terms of financial support and/or accountability.

Means

Consideration of *means* focuses on the methods and standards an integration approach employs as it operates. Decisions about means highlight what an approach takes to be the most rewarding opportunities, pressing challenges, and perplexing trade-offs associated with socio-technical integration. Attention to socio-technical means will underline best practices and raise practical questions about opportunities and challenges that are amenable to empirical analysis. Given the variety across the communities of practice we have chosen as exemplars, we should expect the means to constitute a contextualized

[12] The choice of these four exemplars to represent the four quadrants of our framework is inevitably imperfect and is offered here and throughout the next section primarily for illustration purposes.

[13] Of course, these characteristics are quite fluid and varied, and our association of any specific characteristic with a given approach is somewhat of an oversimplification, especially since a given integrative project may embody multiple *instrumental*, *interpretive*, and *normative* roles (Jasanoff, 2011) that could also shift over time. Similarly, in enhancing communication, an integrative approach may not only be contributing to the *instrumental* selection of means for achieving pre-existing ends; it may also allow for *substantive* opportunities to identify and reflect upon conflicting or diverging *normative* goals (Stirling, 2008).

repertoire of different approaches, practical insights, and design considerations. Our analysis of means is also two-dimensional, addressing (1) the degree to which a community is structured in its engagement with its focal practices, and (2) the degree to which its techniques are fixed in advance. An approach is *structured* to the extent that it engages with a practice in a relatively consistent way each time (Toolbox, VSD), and is more *unstructured* as the type of engagement varies depending on the particular engagement venue or group (Human Practices). Approaches can also combine elements of fixedness and flexibility having a semi-structured method that is topically oriented and therefore locally adapted on each occasion (STIR).

Ends

The *ends* of collaborative integration are the values and norms that motivate and justify an approach's activities. These include helping scientific teams become more efficient and aligned, enhancing the reflexive and socially responsive processes of scientific research and technology development, and working to make outcomes more equitable, democratic, or sustainable. For analytical purposes, we map the ends of collaborative integration along two dimensions: (1) instrumental-normative, and (2) facilitative-substantive. The instrumental-normative dimension tracks the extent to which the integrative effort is conducted for the sake of ends that are valuable as a route to other ends (e.g., economic security) or in themselves (e.g., human dignity). The facilitative-substantive dimension traces the degree to which an approach emphasizes aiding the focal practice in achieving the ends it has set for itself or contributing new and better ends to the focal practice. Some integrative approaches are primarily *instrumental* in that they aim to enhance communication as a means to achieving broader project goals (Toolbox); others attempt to engage in co-labor around specific ethical issues and are more explicitly *normative* in seeking to advance goals, ends, or principles taken to be ends in themselves (Human Practices). We situate commitments to broadening values in technical practice midway between these extremes (STIR, VSD). Along the second dimension, some approaches are more *substantive* insofar as they seek to build general capacities for reflection and deliberation on both ends and means (STIR, Human Practices), while others are focused on *facilitating* boundary-crossing activities (Toolbox) or *advocating* for specific value-adjustments (VSD).

Community	Forms	Means	Ends
Human Practices	Collaborative study, inquiry, and conversation on contemporary technological developments	Ongoing, participant-observation between biologists, ethicists, and anthropologists	Design, develop, and sustain collaboration following principles of emergence, flourishing, and remediation.
STIR	Collaborative description and inquiry embedded within expert practices	Regular, situated semi-structured dialogue between embedded humanist and lab practitioners	Heighten reflexive awareness in order to exercise deliberative and responsive capacities
Toolbox Project	Workshop-based approach that aims to elucidate native socio-ethical dimensions	Structured dialogue method that reveals epistemic, metaphysical, and axiological assumptions	Facilitate improvements in scientific communication and collaboration
Value Sensitive Design	Additional considerations and methods during a design process to address value-based design factors	Conceptual, empirical, and technological modes of 'investigation'	Construct technologies that better serve values and stakeholders by including concerns in design process

Table 1: Forms, means, and ends of collaborative socio-technical integration exemplars

A Comparative Framework

To represent several of the most salient differences, we offer a two-dimensional matrix of *values* and *capacities* (Figure 1). The *values* dimension represents a range of possible ends/forms combinations, from those that seek to enhance the existing goals and commitments of the focal expert practices ("native values") to those that emphasize introducing new goals and commitments for expert consideration ("alternative values"). The *capacities* dimension represents a range of possible means/forms combinations, from those that seek to introduce additional knowledge, content, and resources ("alternative capacities") to those that seek to enhance latent resources and capacities ("native capacities").[14]

14

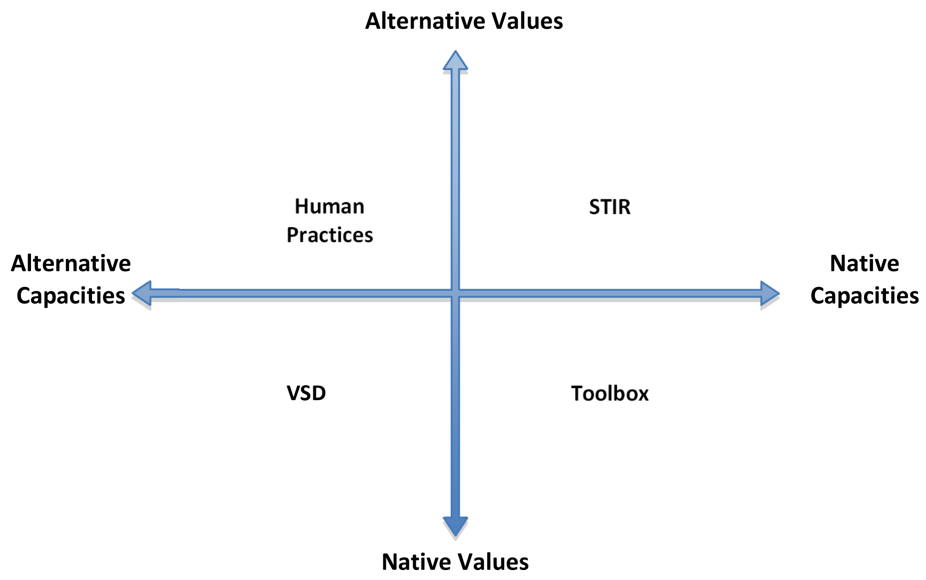

Figure 1. Comparing communities of socio-technical integration by forms, means, ends

To illustrate the features suggested by the four quadrants, we highlight aspects of the exemplars. Thus, Human Practices appears in the upper left because of its emphasis on bringing an ethical disposition that is otherwise seen as foreign or lacking into the natural science research environment, and because this is attempted largely through its own conceptual expertise by way of its own posited ideal (mutual flourishing). VSD is similar to Human Practices in that it emphasizes the introduction of its own expertise, and of additional considerations and constraints; however, since this is often explicitly done to support existing project goals, we locate it closer to native values than we do Human Practices. In the lower right, and also close to native values is the Toolbox Project, which attempts both to enhance local communication capacities and to support local goals, without explicitly calling attention to its own content and expertise. Finally, we locate STIR in the upper right, since it seeks (similar to Toolbox) to enlarge the experience of local experts, but does so (similar to Human Practices) with respect to its own posited ideal (deliberation), hence simultaneously tapping into and broadening native values.

The exemplars are meant to illustrate the various norms and postures within the integrative field more generally. Accordingly, the various quadrants suggest modes of collaborative integration—where "mode" is expressive both of the way integration is pursued and of the envisioned outcome—that can illuminate other approaches not specifically analysed here (Figure 2). Thus, the upper left quadrant suggests a commitment to **reforming** expert technical practices through the introduction of alternative values, voices, and methods. While we have chosen Human Practices to represent this mode of integration, it is also characteristic of much work in action research. By contrast, the lower left focuses on **augmenting** local expert practices and decision-making with additional expert practices, supplementing skills and considerations while working within local problem framings. We find this to be the case not only with VSD, but also with other integrative approaches that emphasize their own expertise, for instance bioethics consultancy and some SRPOISE projects. The lower right represents an emphasis on skill-based learning aimed at **facilitating** teamwork, working with and within local problem framings but in this case without an explicit interest in broadening or supplementing either values or capacities. This is characteristic of the Toolbox Project and of much skill building and aptitude enhancement, such as those seen in approaches to the Science of Team Science. Finally, the upper right suggests a mode of **problematizing** existing practices and commitments: rather than working toward direct reconfiguration and reform, this mode seeks to enhance second-order learning with the assumption that experts will voluntarily broaden and reframe their own problem definitions and adjust their own practices. We have chosen STIR to represent this mode of integration, which is also evident in approaches such as Constructive Technology Assessment.

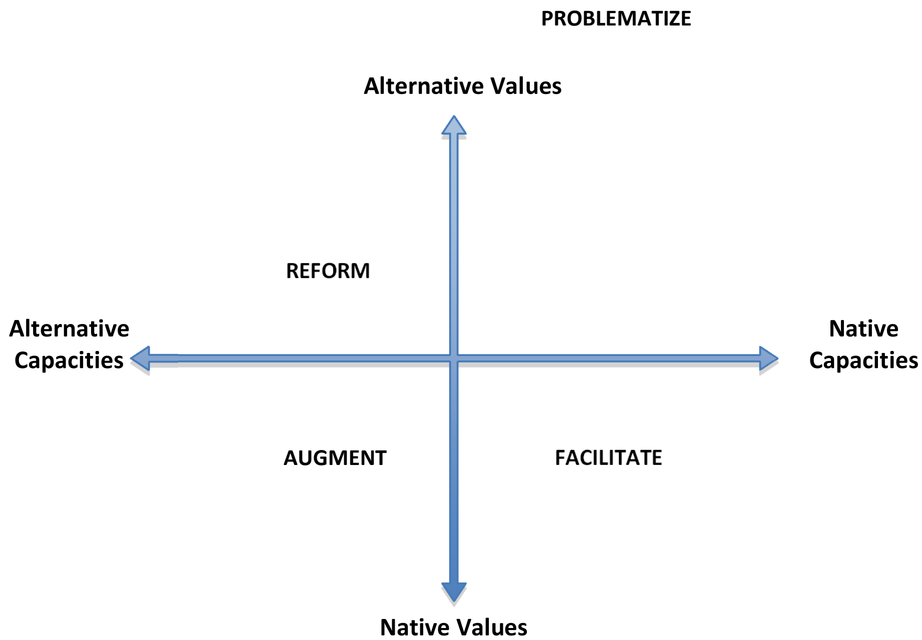

Figure 2. Idealized modes of socio-technical integration

The framework reflects the diversity of methodological tendencies, modes of operation and commitment, and normative justifications in approaches to collaborative socio-technical integration, illustrated through four exemplar approaches. We recognize that the framework does not necessarily capture all aspects of integration (e.g., it does not indicate whether approaches are more or less embedded or more or less structured); furthermore, individual approaches are likely to be richer and more complex than their assignment to an individual quadrant may indicate (e.g., collaborative integration is rarely static and individual approaches may include a breadth of norms and positions[15]). With these caveats, we find this exercise to be valuable in that it suggests how collaborative engagement of expertise can be guided by very different justifications and can engage different aspects and modes of expertise. For instance, we expect that approaches that invoke the reflexivity rationale tend to appear on the right side of the figure insofar as reflexivity, learning, and communication are ultimately rooted in local and native capacities, whereas those that stress the interdisciplinarity rationale will be more concentrated in the left half of the figure insofar as they place more emphasis on the introduction of new forms of expertise into the focal practices. Meanwhile, approaches in the lower half of the figure focus less on questioning pre-determined goals and more on achieving them effectively and efficiently. By contrast, approaches in the top half of the diagram seek to develop new values within expert practices.

The framework can also help anticipate and explain how different collaborative approaches to socio-technical integration can find themselves in conflict or disagreement with the experts in question (as when alternative values are meant to challenge native values), despite appearing to share similar commitments. For example, and drawing on the SEE concepts identified earlier, we suggest that collaborations in the left-half of the diagram, particularly those in the upper left/reform quadrant, are likely to be more challenging than those in the right half, with those in the lower-right/facilitate quadrant being the least complex to manage. The explanation is that, depending on the nature of the collaboration, the technical experts in question will have more or less learning to do, without the incentive of linking this additional work to their own prior commitments. Such an explanation can help illuminate the source of potential difficulties and inform integration design choices in light of what is practicable. Furthermore, seeing expertise as part of a culture and acquired through socialization may help explain why efforts to promote more radical forms of reflexivity or interdisciplinarity are difficult; if responding to alternative values is akin to adopting a new paradigm, it may involve "unlearning" as much as "learning" as domain experts are challenged about things they previously took for granted as part of their contributory expertise (cf. Evans & Marvin, 2006).

Finally, the normative commitments that characterize different collaborative approaches to integration—all of which potentially may be seen as supporting responsible innovation—may tend more toward *disruption* or *reinforcement* of native values, goals, problem framings, and programs. Significantly, our analysis suggests that all integrative approaches seek to address the limitations of technical expertise—and more generally, the limitations of innovation actors and processes—but they proceed from different diagnoses of this limitation and prescribe different remedies. Comparing the quadrants diagonally helps

[15] We have acknowledged such internal dynamics and the fact that one integration approach is not necessarily confined to a single quadrant using clouds surrounding each of the four exemplars. For instance, in seeking to articulate segregated and otherwise excluded values that are nevertheless latent in local expert practices, STIR works with native (scientific research) values as a route toward more consciously addressing alternative (broader societal) values; this results in both native (1st order reflective learning) and alternative (2nd order reflective learning) outcomes (Schuurbiers, 2011; Wynne, 2011).

bring certain tensions to the forefront. A central normative tension thus opens up between the reform mode of integration, which assumes a fundamental lack in the program of those experts with whom they seek to collaborate, and the facilitating mode, which is fundamentally aligned with the goals of programs it chooses to engage. A methodological tension opens up between the augmenting mode of integration, which stresses the importance of other participants and tools, and the problematizing mode, which relies on experts correcting and modulating their own practices based on heightened contextual awareness and second-order reflective learning.

5. Concluding Reflections

We have argued that collaborative socio-technical integration is a form of expert engagement that is distinct from related fields such as trans-disciplinarity and stakeholder engagement in three ways: it (a) addresses variously conceptualized socio-technical divides pertaining to expertise, (b) operates closely within expert practices, and (c) seeks to meaningfully transform those practices. Justifications for socio-technical collaborations are implicitly, often explicitly, tied to the inherent limitations of expertise, which are implicated in how experts relate to broader societal dimensions of their work. Socio-technical integration is thus the intellectual and practical work of inflecting expert values and capacities in order to more responsibly align science, technology, and innovation with their broader societal contexts.

As we have presented it, the field is populated by a diversity of individual researchers and communities of practice that collectively seek to explore and foster such alignment. In order to compare relational, methodological, and normative divergences among diverse integration approaches we presented a framework and illustrated it with exemplar communities of integration. The framework suggests that while collaborative approaches to socio-technical integration all seek to orient expert practices more explicitly to under-specified societal contexts, they do this in the comparatively different modes of reforming, augmenting, facilitating, and problematizing expertise. These modes can be used to compare approaches and foreground their synergies and their tensions. For instance, methodological approaches that seek more directly to *introduce* alternative expertise can be distinguished from those that seek more indirectly to *cultivate learning* within native expertise. Similarly, normative commitments to *broadening* expert practices contrast with those focused on *reinforcing* them.

By extension, the framework suggests that all four quadrants can potentially support responsible innovation. While socio-technical integration is frequently cited as an established mechanism of responsible innovation, the diversity of integrative approaches imply similarly diverse orientations to broader programs of knowledge production, technoscience, and innovation in society. We suggest that the more critical an approach is of the innovation projects it engages, the more it will seek to reform or problematize their fundamental assumptions and values. By comparison, more progressively inclined integration approaches will seek to augment innovation projects, as it were completing them with missing elements. Finally, approaches that are aligned with the goals and values of projects they have chosen to engage will seek to optimize their operational processes to make them more effective at achieving their own stated goals. The point then is not that one type or mode of integrative approach is closer to responsible innovation, but rather that each one can be relatively strong or weak in terms of its support for responsible innovation. In this respect, certain modes of integration may be more prone to specific shortcomings: modes that emphasize alternative expertise are more likely to reify divisions of moral labor (in the augmentation mode) or run the risk of ejection (in the reformist mode); while those that tend to accommodate native values or capacities are likely more easily co-opted (in the facilitative mode) or resisted (in the problematizing mode).

The extent to which an integrative approach supports responsible innovation may depend in part on how effectively it balances an awareness of the different modes of integration and judiciously incorporates this into its own practices. In particular, it is helpful to consider how a given integrative mode enlists its opposite mode as depicted in the framework. Consider the case of the problematize-augment opposition: A problematizing mode that primarily disorients the experts it engages will be less effective from the standpoint of responsible innovation than one that allows this disorientation to become a resource for meaningful reflection and productive decision making moving forward. In this case, the integration agent operating in the problematizing mode may be aided by considering how his or her own tools and knowledge might illuminate enabling questions and practical pathways, something that could be aided by operating temporarily in the opposite mode of augmentation. By contrast, operating exclusively in the augmentation mode runs the risk of reinforcing a problematic division of moral labor, in which technical experts are no longer responsible for the societal and ethical dimensions of their work. To temper this, it may be helpful to incorporate aspects of the opposite mode of problematization, which focuses on reflective and responsive capacity building among technical experts. The same could be said for the reformist-facilitative opposition.

We emphasize that the modes of practice we have in mind are not monolithic and allow for nuanced and complex modes of engagement. In other words, a given mode can encompass critically normative attitudes and instrumentally supporting roles at the same time. The important question of how a given integration approach chooses to balance its manifold relations with native values and native capacities has a more general correlate in how the integration approach is itself balanced with additional activities and structural components that are taken to be more broadly indicative of responsible innovation. These include mechanisms meant to advance inclusiveness, anticipation, reflection, deliberation, and responsiveness at institutional levels that are significantly broader than the expert practices themselves (Owen et al., 2013). Ultimately, the choice and evaluation of collaborative socio-technical integrative modes and mechanisms will require a critical assessment of the social, ethical, and democratic legitimacy of a given innovation program or project as well as a clear sense of how integration is meant to relate to broader goals and criteria of responsible innovation.

It would therefore be helpful for future research on socio-technical integration to develop a more fine-grained account of the diverse techniques employed by various approaches. For instance, whether an approach operates in a manner that is institutionally embedded, institutionally fused, or resembles that of a consultant may play an important role in understanding the range of its application and its comparative strengths and weaknesses. Future studies of integration should also be concerned with evaluating the efficacy of its presumed interventions, especially in light of the broader justifications invoked for them in the first place, and will ideally take a comparative view of diverse integrative approaches. There is also a significant need to develop theoretical accounts of socio-technical integration, both those that seek to explain it and those that seek to critically inform its norms, practices, and reception.

The value of framework for collaborative socio-technical integration lies in its ability to accommodate a considerable diversity of motivations, conceptions, methods, and relationships currently developing around the collaborative engagement of expertise. Taking this diversity into account can lead to more transparency in justification, design, and evaluation of collaborative efforts aimed at socio-technical integration for engaged experts, public sponsors, and affected stakeholders. We do not envision a field that aims at theoretical, methodological, or normative consensus, but rather one that nurtures a mutually enriching discussion among engaged scholars from different disciplinary and problem-oriented traditions around issues that characterize the boundaries of the field. Collaborative socio-technical integration will thereby be more likely to develop with due regard for the cultural and institutional structures that it strives to work within, improving its efficacy without over-promising what it can deliver and mindful of potentially incongruous and even counter-productive outcomes. In our view, this requires a reflexive, critically balanced, on-going, and dynamic interplay between the native and alternative values and capacities that are implicated in any given expert site or innovation project.

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