Systematic problem-specification in innovation science using language

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Abstract

Purpose – Problem specification is a key front-end step in the innovation process. This paper aims to introduce 'purpose-context' – a conceptual framework to systematically explore problem-specification across mapped contexts. The framework's logic is operationalized by the inherent structure of language – its syntax/grammar, which enables the systematic exploration of problem-specification. The method showcases two approaches to structurally explore the vast textual databases available to us today for problem-specification in innovation science, thereby furthering the pursuit of innovation through its foundational elements.

Design/methodology/approach – The conceptualization of the purpose-context framework was guided by logic and the scholarship of integration applied to bodies of work including innovation, design and linguistics. Further, the key elements of the conceptual framework were unpacked and structured using the syntax of language. Two approaches to operationalize the method were developed to illustrate the systematicity of the process. The construct was then validated by using it to systematically specify problems in the technical context of Raman spectroscopy and in the socio-technical context of international development. Overall, this paper is a work of relational scholarship of integration that bridges academic-practitioner gaps.

Findings – The purpose-context framework is well-suited for application in the innovation process with applicability across several abstraction levels. One key contribution is the recognition that a broader problem-specification exercise covering one-one, one-many, many-one, many-many problem-context mappings expands the range of potential solutions (innovations) to address the problem-space. Additionally, the work finds that it is possible to provide structure to the cognitive elements of the innovation process by drawing inspiration from the structure inherent in other cognitive processes such as language (e.g., parts-of-speech, phrase composition). Drawing from language is particularly appropriate as language mediates communication in any collective pursuit of the innovation process and furthermore because a large amount of information exists in textual form. Finally, this paper finds that there is merit in approaching innovation science from its foundational elements – i.e. data, information and knowledge.

Research limitations/implications – While the purpose-context framework is broadly applicable, the methodical approach to provide structure to the front-end cognitive process is 'one' fruitful approach. We suspect other approaches exist.

Practical implications – The purpose-context framework is simple in its framing yet provides innovators, scholars and thought leaders, the ability to specify the problem space with greater coverage and precision. Further, in the solution-space, it provides them the ability to choose the breadth of solution scope (e.g. targeted solution addressing a single problem, targeted solution addressing a set of problems, the combination of solutions addressing a single problem and combination of solutions addressing a combination of problems). In addition, by pairing the creative front-end innovation process with machine power, this study provides a formal method to scale-up the coverage of creativity (and potentially that of solutions to those problems) and reduces the chances of missed/blind-spots in problem-specification. Finally, evaluating

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purpose-contexts leads to 'capability-contexts' – a capability-oriented viewpoint informing capability development decisions such as the focus of R&D programs and related resource allocation decisions.

Originality/value – The paper uses logic to connect multiple bodies of research with a goal to provide systematicity to problem-specification – problem-specification, which is an under-addressed part of the innovation process. The use of data to systematically explore problem-space lends it systematicity (repeatability and measurability) and is therefore, valuable to innovation science. The proof-of-concept demonstrates the conversion of concept into a method for practical application.

Keywords Natural language processing, Language, Idea generation, Innovation concepts, Systematic innovation, Innovation science, Data-driven innovation, Purpose-context

Paper type Research paper

Introduction

The body of literature on innovation has focused on understanding innovation as a phenomenon, asking what is innovation/innovative, what are its various forms/typologies and how are they different from one another. It has not focused equally on the 'innovation process' to research how innovation might be pursued (Kusiak, 2016). Furthermore, a science of innovation, i.e. a structured process of discovery that is systematic, measurable, testable, falsifiable and repeatable, does not yet exist. This endeavor is challenging given the multi-level pervasiveness, vast applicability and complex impact of the innovation phenomenon. However, expanding our understanding of the innovation process has particular salience in today's world where we confront problems of unprecedented complexity and scale (complex socio-technical grand challenges such as food security, freshwater scarcity, climate change, and global pandemics) and we depend upon innovation (multiple innovations at several scales across various interconnected systems) to overcome them. Thus, the motivation of this work is in contributing systematicity and method to the innovation process and/or its parts. We use the generic definition of 'innovation' i.e. 'the development of a solution to a problem' and use the various bodies of literature to conceptualize the innovation process as a two-part process containing a problem-specification phase and a solution development phase. Our focus in this paper is on developing a framework to improve articulation of the problem-space by adding notions of action, modification and contextualization. This paper builds on the theory of innovation, design and linguistics to introduce a methodology that can be implemented to make the innovation process more systematic in practice. Therefore, methodologically, this paper goes beyond Boyer's (1990) scholarship of integration into a relational scholarship of integration (Bartunek, 2007).

We are currently in the midst of a data explosion that will continue to dominate decision-making and impact the innovation process. Tang *et al.* (2016) introduced the 'atomic' elements of innovation – data, information, knowledge, intelligence as inherent components to the science of innovation. We focus our efforts on using data and information, organized syntactically, to systematically pursue problem-specification drawing on two theoretical schools of thought. First, we highlight the ability of a generic interpretation of innovation to link its various conceptualizations. This is followed by the introduction of purpose-context and capability-context as structural interpretations of the problem-space – solution-space. We then draw from language theory and syntactically breakdown purpose-context and capability-context into their linguistic constituents, which builds a link to systematic data exploration for problem-specification. Next, we describe two approaches to operationalize purpose-context, and develop a proof-of-concept by applying it to an innovation process in the domain of 'chemistry'. In addition, we validate the construct by using it to specify problems in the technical context of innovation in Raman spectroscopy, and the socio-technical context of a grand challenge – the adoption of clean potable water by a rural community in the Dominican Republic. Finally, we describe limitations and discuss potential methods to overcome them. Overall, we contribute to the field of innovation science by developing a framework applicable at multiple abstraction levels and providing a systematic method to pursue the front-end of the innovation process.

Think of innovation as a problem-solution couple

At the core of innovation is the development of a solution to a problem. This theme runs through its various definitions that independently conceptualize it as an output manifested in the form of a tangible or intangible artifact (product, service, process, practice, concept and idea) (Tang *et al.*, 2016). While these independent definitions are all accurate individually, conceptualizing innovation more generally as the development of a solution to a problem unbound it. For instance, innovation is neither a solely physical artifact nor is it solely metaphysical, but both (Zaltman *et al.*, 1973). Innovation is neither only a product (Bordegoni and Rizzi, 2011) nor is it only a process, but both (Utterback, 1971; Utterback and Abernathy, 1975). Innovation in not limited to the individual and also applies to groups (research disciplines), organizations (companies), ecosystems (patent-bodies and regions), cities (the city of Barcelona), nations ('the new deal' – a policy-set enacted by President Roosevelt between 1933 and 1936 in the USA, and India's Economic Liberalization policy-set of 1991) (Howell and Higgins, 1990; Tushman and Nadler, 1986; Zheng, 2010). Therefore, innovation is a pervasive phenomenon applicable across several levels of abstraction (Welling, 2007), and a generic definition of innovation – as a solution to a problem – serves well in binding the independently accurate definitions into a cohesive collective, at an overarching level.

Innovation can occur at any system level, but its effects will likely affect several interconnected system components. For instance, a process innovation in a manufacturing organization will likely impact its multiple functions in the form of a revised raw-material flow, revised workflow, revised personnel training, improved processing, improved production times, improved product, impact on the marketplace (suppliers, customers and competitors). Similarly, an innovative idea implemented at the national policy level will certainly impact the economic, social and cultural environment of the governed system. This explains that while studying the impacts of innovation, a systems lens is not only useful but crucial. Interestingly, when a systems lens is used, the scale-free nature of innovation surfaces (Andriani and McKelvey, 2009; Jones, 2005; Poole *et al.*, 2000). Scale-free behavior is characteristic of complex systems – i.e. those that have several interconnected components such that their decomposition is impossible (Ottino, 2004). In complex systems, cause-effects can be estimated through pattern matching but not guaranteed by reproducible proof, and in such systems, phenomena at one level can affect system outcomes at the same or different level. Stated differently, the behavior of the system is the same across the different scales of the system or cannot be attributed/localized at a particular scale. Spencer and Woods (2010) demonstrate the scale-free nature of large-scale idea generation, which has a direct relationship with innovation. This forewarns us against defining innovation at singular scales (local or global), and therefore, conceptualizing innovation more generally as 'the development of a solution to a problem' enables cross-linking its independent definitions agnostic of their scale dependencies. For instance, Engler (2009) and Engler and Kusiak (2010, 2011) define innovation by extending its scope across the system components (agents, actors and artifacts), thereby accounting for the cross-scale impact of innovation and connecting well to process, practice, product manifestations and even to organizational design (Sheth and Sinfield, 2019a). Further, it allows us to link the product conceptualization of innovation to the marketplace (Draper, 2017) – a complex system in itself. This link between technological invention and its associated value in a marketplace has been described by (Kusiak, 2016). Similarly, Schmookler (1966) defines innovation as a technological response to a market need, i.e. a demand-supply phenomenon. Economists (Allen, 1977; Mokyr, 1990b, 1990a) and management scientists (Adner and Levinthal, 2001) agree that innovation is a demand-supply phenomenon but argue against the precedence of one before another. Instead, in their work, innovation is thought of as either a technological supply response to market need and/or a technological solution supply to a latent (unrealized) market need. In other words, technological invention does not need market-value motivation. Support for this argument can be inferred from Arthur's (2009) discussion of the nature of technology where technology is described as the clever and creative manipulation of expected natural phenomena through the use of other phenomena (e.g. – the anti-gravity behavior in a magnetic levitation train – a manipulation of the (expected) natural phenomenon of gravity by the use of electricity). Note that Arthur has no emphasis on the market-related motivation for technology although he provides detailed explanations on how technology affects/interacts with the market. Similarly, Kusiak explains that creativity is demonstrated by artists who may draw joy from the exercise without being motivated by market-value. This is different from innovation, which has the core component of market success (Tidd *et al.*, 1997). Sinfield (2019b; 2010) describes this problem-solution couple and develops a systematic process to approach it in the context of new technology adoption for the state of Indiana, USA.

Underlying all the above interrelated explanations of innovation is 'the development of something new of value (an artifact of value), that has an effect on other system pieces of value (other related artifacts of value) and can then be further developed into something new of value (another artifact of value)'. A nomenclature-centric argument is futile in the context of this paper and is avoided by accepting this common theme underlying the various definitions on innovation, that 'innovation is a problem-solution couple – the creation of something new (a solution) that has an impact (i.e. affects a validated or latent problem)'. In the next section, we discuss two approaches to the innovation process based on the reciprocal relation between product innovation and organizational capabilities – a view that is reflected in organizational studies on innovation (Cooper, 2001; Danneels, 2002).

From problem to solution and vice versa

The literature on design discusses the notions of problem and solution spaces (Dorst and Cross, 2001), in traditional treatment as two discrete parts of a process and in more recent treatment as connected parts that co-evolve together (Maher *et al.*, 1996) with information interchanging between them. As innovation contains creativity, the innovation process thus, has at least two connected and potentially co-evolving parts – problem and solution – that may be iteratively approached from either direction i.e. from problem to solution and/or from solution to problem (Sinfield, 2005). Both approaches necessitate problem-specification. Thus, operationalizing the innovation process requires a focus on uncovering the needs of potential customers/beneficiaries. This is intuitive, yet, problem-solvers/innovators/entrepreneurs would immediately state insightfully that customers are often unaware of their needs or may be erroneously misattributing needs (e.g. Steve Jobs' eschewing market research based on his strong belief that customers often did not know what they wanted). Therefore, we should be wary of confounding problem-specification with need. Instead, an improved approach is to recast the problem as a user's purpose to fulfill/accomplish/achieve. Doing so aids in unearthing the nuances of the marketplace demand and allows innovators the freedom to explore solutions to satisfy them thereby leading to increased novelty. While insightful, this is not new. Theodore Levitt's famous quote "people do not want to buy a quarter-inch drill. They want a quarter-inch hole" delivers this very message about focusing on a customer's purpose to fulfil. In fact, the literature on general purpose technologies provides this insight in relation to economic growth (Bresnahan and Trajtenberg, 1992; Helpman, 1998; Jovanovic and Rousseau, 2005; Lipsey *et al.*, 2005). What is not as clear, however, is the variance of the user's purpose in accordance with a variance of the user's context. For instance, a single independent traveler *exploring a new city* is likely to find value in staying at a bed and breakfast offering listed on Airbnb.com given several performance parameters the traveler would find valuable (lower than hotel rates, larger living space, the experience of living in a locality, the potential of finding information on local delights at the Airbnb, personalized service and at home feeling) in comparison to staying in a hotel. Conversely, a single independent traveler *attending a business conference* is more likely to make a hotel room reservation given the higher importance of a different set of performance parameters (ease of access to the conference activities, unconstrained opportunity to network at the event, full-service room and laundering facility). For both travelers, their apparent purpose was finding a place of refuge, but the difference in their contexts highlights the different points of value sought by potential customers. The context adds richness to data, enables us to transition from data to information and into 'what is valuable to the customer' expanding the purpose-set. Thus, situating users' purpose in their context leads to a richer characterization of the problem to be solved. Note that here the abstraction of context is at the level of the individual person with the *locus* of innovation being a tangible product of value to the individual. However, as is explained in forthcoming sections, contextualization of purposes can occur at various other abstraction levels and with various artifacts as the loci of innovation.

Above, we discussed firms developing capabilities to enable innovation (Wang and Chen, 2015). Conversely, the literature has also discussed the impact of firm capabilities on innovation (Chandy and Tellis, 1998; Dutta *et al.*, 1999; Gatignon and Xuereb, 1997; Moorman and Slotegraaf, 1999; Souza *et al.*, 2004; Srinivasan *et al.*, 2002). Approaching the innovation process from solution to problem highlights the supply-side power of technological invention and creativity. In addition, it lays importance on the firm's dynamic capabilities (Eisenhardt and Martin, 2000) that lead to its sustainable competitive advantage (Barney, 2000, 2001; Nelson, 1991; Peteraf, 1993) in dynamic contexts. We are surrounded by several 'market-shaping' and 'market-creating' inventions that make the case for the supply-side power of technological invention. For instance, the mobile telephony industry developed the smartphone that essentially embedded telephone communication in a hand-held computer. Apple Inc. further embedded a camera, music player, measurement devices, compass and more on a hand-held computer to create the iPhone. Before the iPhone users were seemingly satisfied making separate purchases for a computer, a music player, a camera, a compass. The average user is now unlikely to return to making separate purchases – a basic mobile phone with only calling capability, a point and shoot camera, etc. Apple's innovation was in creating a market from its technological inventions. It can be said that Apple served the latent needs of the marketplace through its solution. Thus, the supply-side power of inventions cannot be ignored in the study of a process for innovation. Formally, and in alignment with design studies, this can be interpreted as using the innovator's capability to develop a class of solutions (those with a defined set of features) mapped to the customer's purposes in user context/s. For example, in the case of Apple's iPhone, the company pre-possessed the necessary asset-base (software and hardware development skills, operational expertize, direct-to-consumer sales expertize and management experience) required to develop a consumer-electronics product. It used this expertize and enabled the many-in-one combined smartphone that found customers forming the mobile phone market, originally dominated by purely telephony companies such as Nokia and Motorola, the music player market originally dominated by SONY, the point-and-shoot camera market originally dominated by Canon and Nikon. Thus, Apple was able to activate latent purpose-context pairs based on its capability set. In other words, it approached innovation from solution to problem. The notion of context in the solution-to-problem approach is as significant as that in the problem-to-solution approach. This is because in the solution-to-problem approach, solution development capabilities are determinants of the produced artifact. In many cases, innovators (individuals/organizations/nations) make decisions to invest in capability building and acquisition that is determined to be crucial/beneficial in developing future solutions for foreseen/suspected/predicted future contexts. In the case of Apple's market shaping iPhone, software development capabilities were gradually built/acquired in the years leading up to the iPhone. Apple was the pioneer in creating a software developer ecosystem, and has been regularly hosting its famed WWDC (Apple Worldwide Developers Conference) since 1987! The WWDC is a definite catalyst in Apple's decision to venture into a software-dependent revenue generation strategy – its reliance on software as a driver of revenue when it was primarily perceived as a hardware manufacturing company. Apple is still the market leader in revenue generated per app among smartphone makers. This explains how Apple was successful in predicting the software-centric nature of future demand and used its understanding of the context in its capability building process. Hence, capability-context is useful in the solution-to-problem approach, where context should be used to interpret future states of customer purposes, which is different from its use in the problem-to-solution approach, where context is used as a differentiator of customer purposes. Both uses, aid in problem-specification.

The two approaches should not be compared with the co-evolutionary process interpretation evident in the literature on design. There the focus is on the process of design and its iterative nature between problem and solution-spaces, whereas the two approaches explained above describe approaches to innovation and its interpretation as purpose-context and capability-context structures helpful in problem-specification and solution-development. However, borrowing from the design literature to view problem-specification and solution-development as two co-evolving processes acknowledges the iterative nature of the innovation process also detailed by Sinfield (2010). Maher *et al.* (1996) call this co-evolutionary process an exploration where plausible solutions to some problem from the problem-space are searched for in the solution space, and features and constraints of the solution under consideration become new criteria that lead to the refinement of the problem-space. They explain similar arguments regarding higher-order refinement of the problem-space as made by us with regard to purpose-context above. This is a potential research avenue to pursue in further exploring the innovation process but is not pursued in this paper. In summary, the innovation (problem-solution couple formulation) process can be said to consist of a series of iterative sub-steps encompassing purpose exploration (problem-space characterization into problem-specification) and solution exploration (solution-space characterization via solution search, combination/re-combination and solution selection) and implementation. Further, the role of context is crucial and beneficial in both. Therefore, the innovation process can be structured into purpose-context exploration and capability-context exploration sub-processes, which meet to yield action/impact. In the following section, we discuss the role of language in further unpacking the purpose-context and capability-context sub-processes.

Using language to structure purpose-context and capability-context

Language mediates societal communication, and communication of needs and capabilities is considered a stimulant and/or limiter of a firm's potential to innovate (Utterback, 1971). All our thoughts, desires, needs, purposes are communicated to subjects via some language. Language encompasses indications via signaling (sign language), indications via sounds, incoherent and coherent, where its alphabet – a finite set of symbols out of which words, phrases and sentences are created to represent tangible and intangible substances such as things, their properties, actions performed to modify those things and their properties. At its most basic level, language is a sequence of sounds emitted that take a meaningful form to convey some information ((Raskin and Weiser, 1987) chapter 4). To achieve this, language must have a highly complex and sophisticated organization ((Raskin and Weiser, 1987) chapters 4 and 7). The smallest unit element of language is a unit of sound and is known as a phoneme (Bender, 2013; Twaddell, 1935). Arrangement of phoneme sequences would yield infinite sequences, and therefore, for cognitive simplicity, language has levels of linguistic representation (e.g.- arrangement of phonemes and their variation to yield words and arrangement of morphemes (morphed words) and their variation to lead to sentences) (Schooneveld and Chomsky, 1957). The complex and sophisticated structure of language is born out of the morphology and syntax of language. Between morphology and syntax, English has a relatively higher syntactical dependence in comparison to other languages such as Russian or German (Raskin and Weiser, 1987). For instance, a basic phrase/sentence in English has the structure of subject + predicate + object(s), which is not the case for other languages that have greater morphological dependence. Syntax is a higher-level organizational construct and deals with entities that consist of words including word combination, phrase and sentence. Theories of strong and weak compositionality of language also acknowledge the relationships between the meaning of expressions and their syntactical structure (Fodor and Lepore, 2002; Frege *et al.*, 1982; Montague, 1970; Pylkkänen and McElree, 2006; Traxler and Gernsbacher, 2011). Syntax provides structure to language and language mediates communication. Hence, we argue that the innovation process has much to learn from language, beginning with its syntactic structure.

Language contains syntax, semantics and pragmatics – three progressively complex constructs of communication (Shannon and Weaver, 1949). 'Semantics' is a separate linguistic discipline that deals with the meaning of everything in a language that has meaning (Bender and Lascarides, 2019; Raskin and Weiser, 1987). It operates at all the hierarchical levels of the language i.e. morpheme, word, phrase, sentence, paragraph, text/document. However, the syntactical structure of language introduced above i.e. the grammar, cannot be interpreted as semantics. As Chomsky illustrates, (1) and (2) below are two sentences. While (1) is grammatically accurate and (2) is grammatically incorrect, both have equal and no meaning i.e. they are semantically incorrect. (3) Is the title of a work on the importance of punctuation (Truss, 2003) and yet another instance of a syntactically correct sentence misleading semantically:

- Colorless green ideas sleep furiously.
- Green sleep colorless furiously ideas.
- The Panda eats, shoots and leaves.

Thus, semantically-based definition of 'grammaticalness' is futile (Schooneveld and Chomsky, 1957). But still, the syntactical structure of the grammar is itself highly useful to us. This is because it provides the ability to decompose language into its components at various levels of linguistic representation (Bender, 2013; Schooneveld and Chomsky, 1957). This decomposition into rules leads to a possibility of a schema that could then produce/generate new phrases/sentences. This is akin to a rule-based finite-state machine i.e. an automated model that can simulate sequential logic (Hopcroft *et al.*, 1979). However, English is not a finite state language – i.e. a finite-state device (e.g. schema) can never produce all and only the grammatical sentences of English; yet broken phrases in English are helpful in conveying meaning without complete syntax. It is plausible to think of such a generative schema to yield broken phrases that are 'useful' if we picture a foreigner's attempt to communicate partially broken sentences and the recipient's ability to interpret and understand its semantic component and the resulting survival in a foreign country with limited understanding of language. Thus, a simplistic grammar that takes the form of a finite-set Markov process and produces sentences left to right will produce sentences and non-sentences. As the finite-set process would not produce all sentences of a terminal language (Theorem 1 – syntactic structures), it will simply not produce several (all) grammatically correct sentences used in the English language currently, and therefore, is not adequate to represent higher-level linguistic representations of English. Yet, it presents the minimal linguistic theory that merits serious consideration (Schooneveld and Chomsky, 1957), for lower-level linguistic representation. As Chomsky explains, it is the simplest type of grammar, which, with a finite amount of apparatus, can generate an infinite number of sentences. Analyzing the constituents of a sentence/phrase (parsing it), Chomsky (Schooneveld and Chomsky, 1957) defines terminal languages and derives that each phrase/sentence is retraceable into noun-phrase (NP) and verb-phrase (VP).

- The traveler explored the new city

For instance, (4) can be broken into an NP – "the traveler" and the VP – "explored the new city" as shown in Figure 1. A detailed review of syntactic parsing is not warranted herein. However, at a simple level, it should begin to become evident that NP and VP are similar in representation to the notion of purpose discussed above. For example, the VP – 'explored the new city' is representative of a purpose – "explore a new city". We, therefore, formally define a low-level linguistic representation of a purpose as "DO-THIS". Similarly, in a different domain, for instance, in metal casting, the activity of "cutting a metal" is an example of the purpose representation "DO-THIS". Analogous to Chomsky's finite-state language, a very large set of purposes can be defined combinatorially that would generate problem-spaces constituent to the innovation process. It is conceded that this set will not comprehensively contain all the purposes and will contain several that are unlikely to make semantic sense. Yet, the ability to structurally generate purposes for future problem-space characterization based on language merits serious consideration because of the inherent systematicity, and

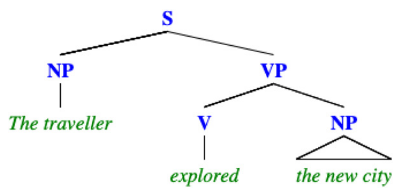

Figure 1.
Syntactic parse tree showing NP and VP components

potential to repeatedly do so in various problem domains. This is of particular importance to innovation science.

A complementary approach to the bottom-up combinatorially generated VP purposes is to use the collective knowledge of rule-based syntactic parsing and the rapidly growing research on parsing using machines. Dependency parsing is one text-parsing method and a promising avenue to use the existent textual data and mine for VPs to extract purposes. The parsed and mined VPs would help in at least two ways – by generating purposes (via extraction) (in a bootstrapping manner) and by validating combinatorially generated purposes. The latter is important because as discussed, it is likely that bottom-up generation of purposes via a Markovian process that will lead to several purposes that could be non-sensical. However, the extraction method operates on data that is existent and is therefore, sensible. Metrics (one of which is statistical/count-based) could then be used to distinguish between the sensible and potentially non-sensical purposes. It remains to be seen how an ordering of the sensible purposes could be done using the extracted purposes. It must be noted, however, that generating purposes via extraction is dependent on the input data i.e. the coverage of the corpus being processed. For VP extraction, we would parse a verb and the verb's direct object (noun). These two combined would yield a purpose. Other rules include navigating a parsed tree across verbs, which may be treated as the head node and its children nodes that satisfy specific dependencies (for a dependency parse) such as 'object predicates' or 'prepositions' or 'prepositional objects'. For instance, Sentences (5)–(10) in Table 1 below showcase sentences expressing the same idea in different but structurally similar ways. The variant tenses and paraphrases of the same idea can yield the purpose "book a room" by extracting them in a rule-based fashion. In some paraphrased cases such as (10), extraction by rule yields not the exact same purpose, however, the interpretational variance between "book a room" and "book a night" is not a matter of concern as they belong to the same problem-space. Lin (1998) uses a similar rule-based method to cluster similar words in an automated process.

Context

Context is key to interpretation. Think of a 'stop' sign in two contexts – one when it is standing upright and another where it is being manufactured in a plant. When a driver sees a stop sign on the road, it is interpreted as an instruction to 'stop here' or else face

Table 1. Parsed dependencies between sentence components on illustrative sentences. The notation nobj, nsubj and nsubjpass refers to nominal object of the verb, nominal subject of the verb and nominal subject of the verb in passive voice. The notation is standard in linguistic parsing

(5) To book a room for one night	Verb – nobj (noun)
(6) A room has been booked for one night	Verb – nsubj/nsubjpass (noun)
(7) Booking a room for one night is a hassle!	Verb – nobj (noun)
(8) Has a room been booked for one night?	Verb – nsubj/nsubjpass (noun)
(9) I want to book a room for one night	Verb – nobj (noun)
(10) I want to book one night in a room	This needs to be paraphrased to get an exact result as above results – "book a room" If verb – nobj(noun) is used, it yields – "book one night," which can then be interpreted

consequences such as meet with an accident or pay a fine for violating a traffic rule. A fresh out of production stop sign still reflects its inherent meaning 'to stop.' However, as it is out of context, it lacks interpretation. This example is applicable to a word in its geographical context. Similarly, for sentences, words hold inherent semantic meaning but without a context (delivered by other surrounding words), interpreting the message of the sentence becomes very difficult. Hence, context operates to bridge the semantic meanings of syntactically arranged words/signs/objects to yield an interpretation for communication. The notion of context is addressed in multiple and separate fields such as design, new product development and natural language processing that interpret data and information to develop knowledge and solutions. This is because context helps convert data into information (e.g.- information extraction via mining), thereby providing relevance to the data (e.g.- use of mined information for market segmentation) and making the entire task actionable. The data along with context becomes information i.e. that which is useful to the operator in decision-making/designing/solution creation. In design, a designer's constraints are often set via the contextual information. For example, an architect requested to design a house works with contextual factors such as the size and topography of the land, soil conditions, water-table levels, neighborhood, wind and sunlight directionality, local climate, the client's taste. The same is true for other fields of design. In new product development, market segmentation exercises often depend on contextual information. In natural language processing – contextual information helps in meaning disambiguation. For instance, the polysemous word 'bank' may refer to a financial institution or a natural formation such as a riverbank and its appropriate interpretation is possible by knowing its situational use i.e. the words surrounding it (Martin and Jurafsky, 2000). Thus, context is critical in the conversion of data into usable and applicable information, at which level, knowledge can be used for action by interpreting the information. In addition, context is a multilevel concept, i.e. it can be simultaneously abstracted at several levels. For instance, the example context for the polysemous word 'bank' helps disambiguate its meaning but this is at the word level. At the sentence level, the information represented in a set of words may be contextualized based on surrounding sentences. Paragraphs and chapters in a book surrounding a paragraph of interest contextualize the information expressed therein. Similarly, past events contextualize current and future events. From the perspective of general innovation – any artifact solution to a problem – any/all contextualization seems significant. The purpose-context framework is able to capture problem-solution at the multiple levels of abstraction.

For the systematic process, for problem-specification explored herein, we abstract contexts at the level of the word with the *locus* of innovation being a tangible product or process artifact. Contexts are situations wherein purposes arise. Complementary to purpose structures 'DO-THIS', contexts are their locational or situational features, and therefore, complete the purpose-context structure to 'DO-THIS-HERE'. Furthermore, the sensibility and applicability of purposes depending on the contexts in which they are situated i.e. specific purposes make more or less sense in specific contexts. Alternately, we might say that contexts ask questions of situational nature such as 'where?,' 'when?,' 'with whom?' In terms of parts of speech, a context cannot be a verb, adverb or adjective but is generally an NP. This makes it cumbersome to create a set of finite NPs as these are simply too many. However, contexts are domain specific and this property makes their operation simpler. Context can be abstracted at several levels and this reflects its large-scale application. This works well as we know innovation occurs at several levels, and therefore, purposes too are applicable at various levels of abstraction. For instance, the outcome of physical and/or meta-physical innovation can be a changed artifact for a consumer-level context or for an industry-level value chain context or for a sectoral-level context or for an economic policy-level context. Studies on innovation have classified contexts into abstraction levels because doing so helps identify the various contexts in which innovation are embedded and better understand the multi-level implications of innovations for policymaking (Binz *et al.*, 2014; Binz and Truffer, 2017; Coenen *et al.*, 2012; Gosens *et al.*, 2015; Kivimaa and Virkamäki, 2014; Markard *et al.*, 2016; Markard and Truffer, 2008; McDowall *et al.*, 2013; Meelen and Farla, 2013; Sandén and Hillman, 2011; Suurs and Hekkert, 2009; Wirth and Markard, 2011). Abstraction as a cognitive process of organizing constructs at various cognitive 'levels' is philosophically well-studied (Burgoon *et al.*, 2013; Floridi, 2008) and its effectiveness when used in synthetic tasks such as configuration, design and planning has shown to successfully improve them via efficiency gains in similarity assessment, retrieval and adaptation (Bergmann and Wilke, 1996). Thus, using levels of abstraction (from activity level upwards to a logical level and further upwards to a conceptual level) to map innovation contexts (ranging from concrete cases, to their logical insights and to even higher-level generalized cases) clarifies the multi-level implication of innovation. Alternately, the outcome of physical and/or meta-physical innovation may span several contexts at the same abstraction level. While addressing technological innovation systems Bergek *et al.* (2015) discuss them and their interactions in wider context structures such as technological, sectorial, geographical and political. Sinfield *et al.* (2020) introduce P^3OE^3TS – a framework for contexts based on a synthesis of several years of efforts in framing complex socio-technical challenges based on the study of patterns emerging from successful innovation efforts (Sinfield and Solis, 2016a, 2016b; Solis and Sinfield, 2015). P^3OE^3TS is an acronym for 'psychology', 'physiology', 'politics', 'operations', 'education', 'environment', 'economy', 'technology', 'sociology', which are considered comprehensive viewing lenses for various contexts applicable to decision-making for Grand Challenges. These contexts are also considered in the design literature (Norman and Stappers, 2016; Sinfield and Solis, 2016b). The above are examples of a range of contexts at the same (policy) level of abstraction. The example of the single independent traveler was an example of contexts at the customer level of abstraction. To illustrate contexts, think of a team implementing the innovation process at the level of a new healthcare product artifact. Here, the abstraction level is that of the consumer. At this level, healthcare solutions may be hierarchically divided into physical solution and meta-physical solutions. Furthermore, physical solutions would be sub-divided into those that are ingested, applied on the body, applied externally and passively consumed, applied in an invasive manner, applied in a non-invasive manner. Given the domain specificity and multi-level abstract-ability of contexts, the organization implementing the innovation process should select situational nouns specific to their domain of interest and at abstraction levels suitably aligned with their objective to generate contextual possibilities. This would lead to a manageable and focused list of contexts. In addition, this also leaves the decision of the breadth and depth of domain coverage with the model operators who are likely familiar with the domain, if not subject matter experts. It seems that wide domain coverage might be beneficial when looking for potential demand in new spaces whereas depth might be beneficial while searching for potential demand in well-served spaces.

In summary, context plays an important role in interpreting data and elevating it into a device for decision-making across seemingly disjointed fields. This ability of context to differentiate purposes and specify problems is useful in interpreting purposes in the innovation process. Thus, understanding the context surrounding purposes should aid in teasing out their nuances and is therefore, critical for a rich innovation process. A purpose-context pair has a 'DO-THIS-HERE' linguistic structure, where 'DO-THIS' represents a purpose and 'HERE' represents the context. Further, purposes are VP-NP combinations that may be combinatorially generated bottom-up or extracted from text corpora top-down.

Contexts on the other hand, help bring out nuances of purpose and generate different purposes from similar VP-NP purpose combinations. Contexts are infinitely many to generate or extract comprehensively but can be categorized to several levels of abstraction. In addition, contexts are domain specific. These two properties allow innovation process implementers to control the volumes of purpose-context pairs to be analyzed.

Capability-context

As introduced above, capabilities are specific processes known to a firm that allows it to create specific solutions. One such process is new product development and a firm's capability to perform specific sub-processes leads to the creation of solutions. Thus, capabilities lead to solutions to problems in specific contexts. Further, it is known that a prominent mechanism for innovation is via solution combination and recombination (Carnabuci and Operti, 2013; Galunic and Rodan, 1998; Kaplan and Vakili, 2015; Karim and Kaul, 2015; Petruzzelli and Savino, 2014) also referred to as recombinant innovation (Tidd *et al.*, 1997). Thus, to a firm that possesses developed solutions, the set of pertinent questions would include:

Q1. Can solutions to certain problems be applicable to other similar problems in different contexts?

Q2. Can a combination of two or more solutions (potentially from different contexts) become a solution to some problem?

Q3. Can a combination of two or more solutions (potentially from the same/similar contexts) become a solution to some problem?

Q4. Can a combination of two or more solutions addressing the same problem lead to an improved integrated solution to that problem?

Q5. Can a modification of a solution to a problem in some context be applied to another problem in a different context and lead to innovation?

Hence, it becomes important for firms to know, which of their solution capabilities suit what contexts. Capability-context thus, becomes – Can we Do-This-Here? Or reversed – 'where can we Do-This?' to frame the activity as a search. The part-of-speech representation of capability-contexts is similar to purpose-contexts in that both can be syntactically parsed into VP-NP combinations. However, unlike purpose-contexts, capability-contexts are unlikely to be a one-one mapping because capabilities are developed for a specific set of contextual characteristics. In addition, the range of contexts in which a capability can successfully be applied must be defined by its careful study on the part of a firm's capability developers. A firm would define sets of contexts wherein the particular capability is applicable and those wherein it is not applicable. It thereby belongs to the 'solution to problem' approach defined above.

Summarizing the above sections, we develop a notion of innovation as a problem-solution couple that can be abstracted at various contextual levels and approached circularly either from problem to solution or reverse. Further, we justify our representation of a problem as a purpose-context pair and use linguistic knowledge to unpack purposes and contexts. This is the gateway to the use of data available in textual form, to generatively yield context specific problems. We then complete the system by describing capability-contexts and their linguistic sub-structure. We use the mediating nature of language in communication to generatively yield problem-specification in two ways – combinatorially and via extraction. The key contribution is in furthering innovation science by developing a repeatable and systematic process for a key step of the innovation process – problem-specification – that is rooted in data, information and knowledge.

In the remaining sections, we demonstrate proof-of-concept by applying the purpose-context framework and linguistic structure to yield specific-problems both combinatorially and via extraction. The sections describe the domains of choice and the methodical details. Finally, we show how the purpose-context construct was helpful in specifying the problem space for technical innovation in Raman spectroscopy and also for a socio-technical challenge of fostering potable water adoption by a population in a rural village in the Dominican Republic, in which there is a longstanding practice of collecting rainwater for consumption.

Methods to systematically generate purpose-contexts

The purpose-context framework emphasizes the notion of performing an 'action' on some 'object' to modify a certain 'property' in some 'context.' In its expressive form in the English language, purpose-context is represented as a DO-THIS-HERE phrase. Purposes are representations of DO-THIS, and contexts are locational or situational and represent HERE. Purpose-context is thus, representative of specified problems. The phrase alludes to a more detailed linguistic link between the expressive form and structured syntactic modules of language such as Parts of Speech (VP and NP). In this section, we will take two approaches – combinatorics and extraction – to implement the purpose-context framework and thereby showcase its potential as an innovation method via proof-of-concept. We choose the domain of chemistry and performing operations to chemically modify a certain material property in chemistry-related contexts. All examples developed in the following tables are illustrative in nature, and therefore, non-exhaustive.

Generating purpose-contexts via combinatorics

The first approach via combinatorics builds purpose-context pairs bottom-up where the model operators (who are expected to be subject matter experts or at least familiar with the application domain) possess adequate control on the exploration of the domain via the use of knowledge of the English vocabulary pertinent to the domain. Purposes, which are represented as 'DO-THIS' and speak to property modification actions on objects lead us to look into the English vocabulary for a set of action words, set of objects and their properties to be modified. 'DO' is an action representation and is generally captured by verbs. While the English vocabulary contains more than 1,500 verbs, some verbs act as categorical representations of several other verbs, and therefore, capture the core thought behind a purpose. We manually cluster verbs into eight active verbs/verb-pairs that capture the broad action intent of the several verbs in English. Table 2 is an illustration of the list of

Action categories (DO)	Actions (DO)
Produce	Make, provide, build, create . . .
Modify	Increase, enhance, arrange, fix, repair . . .
Maintain	No change, transform, treat . . .
Allow/prevent	Admit, include, bar, block, deny . . .
Activate/de-activate	Catalyze, accelerate, mobilize, prepare, condition, familiarize . . .
Collect/distribute	Aggregate, integrate, consolidate, gather, accumulate, assemble . . .
Exchange	Swap, trade, transfer . . .
Detect/conceal	Find, observe, reveal, unmask, spot, uncover, diagnose . . .

Table 2.
Illustrative list of verbs capturing actions and action categories

English verbs and the eight categorical verbs/verb-pairs. Here it should be noted that the clustered verbs capture archetypal action ideas.

The 'THIS' part of the purpose structure should capture the object 'property' to be acted upon. We use the general categorization of physical, chemical, mechanical, electrical, acoustic, biological, thermal, radioactive and optical properties of matter to yield a set of 40 object properties (illustrated in Table 3) that potential customers and/or innovators in the chemistry domain would care about modifying. The table is an illustrative list of properties to modify and combinatorially would yield a larger set of action-property pairs. It is important to note here that the control on the breadth of coverage is firmly within the hands of the framework applicators. They can choose to expand the set by including more object properties to be modified or reduce it. Together, the action and object properties form the purposes half of the purpose-context structure, which is represented as a list (Table 3).

The final step is contextualizing the purpose i.e. the 'HERE' part of the framework. As explained in detail in the sections above, contexts are further specifications of the problem and need abstraction. 'HERE' can be an application object such as "from the carpet", "in the chassis"; a location where the object is used such as "on the road", "inside the home"; a technical or application constraint of the object such as "at low cost", "without maintenance" or it can also or be a social context such as "with friends", "in a group". Importantly, abstractions could take a variety of forms and once again place the onus of coverage on the framework implementer. Here we abstract the purpose at the level of the individual and apply it to the modification of properties of things related to a person or locations visited by the individual. Collectively an illustration of purpose-context pairs is presented in Table 4 as derived bottom-up.

Generating purpose-contexts via extraction

A second approach to generating purpose-context pairs for problem-specification in a domain is via extracting them from a collection of text documents that contain domain data.

Table 3. Illustrative list of nouns capturing properties and action-property pairs

Properties (THIS)	Action – property pairs (DO-THIS)
Weight	Modify weight, maintain weight, conceal weight . . .
Largeness	Produce largeness, allow largeness, prevent largeness . . .
Denseness	Remove denseness, collect denseness, exchange denseness . . .
Looseness	Maintain looseness, modify looseness, remove looseness . . .

Table 4. Illustrative list of nouns representing objects and action-property-object pairs

Object (HERE)	Action-property-object pairs (DO-THIS-HERE)
Alarm	Produce-loud-alarm, create-weak-alarm, maintain-loudness-alarm . . .
Clock	Build-accurate-clock, fix-slowness-clock . . .
Banknote	Prevent-old-banknote, enhance-firmness-banknote . . .
Battery	Maintain-old-battery, collect-rust-battery, polish-large-battery . . .
Book	Collect-dense-book, reduce-dullness-book, reduce-weight-book . . .
Bottle	Activate-nutrients-bottle, collect-enzyme-bottle, exchange-fluids-bottle . . .
Brush	Remove-lint-brush, enhance-bristles-brush, prevent-tangle-brush . . .
Camera	Maintain-weight-camera, reduce-bulk-camera, fix-sharpness-camera . . .
Room	Detect-odor-room, increase-cleanliness-room, reduce-clutter-room . . .
Library	Maintain-volume-library, reduce-noise-library, build-data-library . . .

Similar efforts recently made in the field of natural language processing have shown positive results (Hope *et al.*, 2017). This is a top-down acquisition method where we rely on the information contained within the document collection and the inherent syntactic structure of the sentences therein. Furthermore, syntax has been used to define a word's context in seminal works in linguistics (Harris, 1968). We studied literature on the syntax of language and grammar that are useful in parsing sentences into their sub-components. Parsing methods have been developed in the field of linguistics and computational linguistics for as long as the study of syntax has existed (Chomsky, 1965; Raskin and Weiser, 1987; Schooneveld and Chomsky, 1957). The literature on syntax decomposes a sentence into a parsed tree structure regardless of the parsing technique chosen (e.g.-constitutional parsing and dependency parsing). Each parsed sentence tree has a 'root' node – the topmost node. The nodes in the tree structure are referred to as the 'head' and 'children' where there maybe one or more heads at a single level linked to 'children' nodes creating an 'arc.' In a dependency-based parsing, these links would be referred to as 'dependency arcs' where the dependencies are well-defined relationships between the head and child node. For example, Figure 2 represents the dependency-based parse tree for the general sentence "chemistry is a scientific discipline involving elements and compounds."

We develop a set of rules to organize dependency-based parsed sentences from a developed corpus into purpose-context pairs. A partial set of rules is included in Table 1. To illustrate the method, we implement it over a general corpus of documents developed from Wikipedia pages related to 'chemistry,' thereby showcasing how the purpose-contexts framework can be applied either internally by an organization or to spur open innovation (Chesbrough, 2003). Our corpus includes Wikipedia pages on topics shown in the List of Wikipedia pages that were used to build the corpus for the purpose-context extraction illustration. Tables 5-7 illustrate the action-property, action-context and property-context pairs extracted from statements contained in the Wikipedia pages on 'chemistry' and its listed sub-disciplines [1]. The data and information contained on these pages was parsed

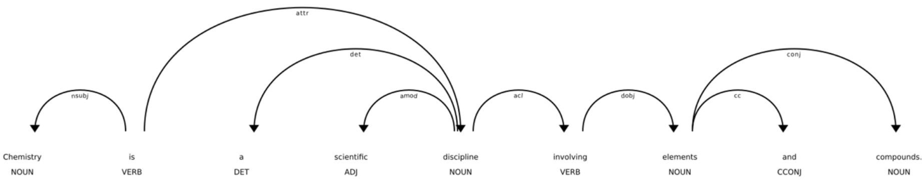

Figure 2. A dependency parse for a sentence from the Wiki page on chemistry

DO	THIS	HERE
Absorb	Gases	
Absorb	Nitrogen	
Accelerate	Body	
Accept	Proton	
Accommodate	Electrons	
Accomplish	Reactions	
Accumulate	Charge	
Achieve	Configuration	
Achieve	Synthesis	
Add	Catalyst	
. . . ~2,200 more		

Table 5. Illustrative list of extracted action-property pairs from Wikipedia 'Chemistry' corpus

using derived rules to yield pairs of DO-THIS, which typically captured 'actions' and addressed "do what?"; DO-HERE typically captured actions and addressed "do where?" and "do how?" contextualizing the action; THIS-HERE captured 'things' and addressed "what-where?" and "what-how?" contextualizing the thing. The tables are illustrative examples of a significantly larger extraction. Therefore, publicly available data on a knowledge database such as Wikipedia can lead to meaningful purpose-context pairs useful in problem-specification via extraction. Hence, framework implementers, innovators in organizations and other practitioners who own their own data or can source a curated set of documents of interest can apply the same method to extract meaningful purpose-context pairs. Importantly, drawing on external data in this way can help facilitate open innovation in a systematic manner (Chesbrough, 2003; Enkel *et al.*, 2009). The key limitation of the top-down extraction approach is in the limitation imposed by information contained in the corpus. Hence, implementers can spend effort to locate key information sources and develop a curated corpus for extraction to achieve desired results. Further, implementers who have access to documentation for their organizational capabilities can use those to approach from solution to problem.

List of Wikipedia pages that were used to build the corpus for the purpose-context extraction illustration.

Wikipedia category: Chemistry

Analytical chemistry, atomic theory, biochemistry, chemical bond, chemical equilibrium, chemical formula, chemical industry, chemical law, chemical reaction, chemist, chemistry,

Table 6. Illustrative list of extracted action-context pairs from Wikipedia 'chemistry' corpus

DO	THIS	HERE
Abolish		In which
Absorb		At frequency
Absorb		From surrounding
Absorb		In amount
Absorb		In proportion
Absorb		In reaction
Accelerate		To speed
Accept		At cathode
Accept		During process
Add		To base
. . . ~3,700 more		

Table 7. Illustrative list of extracted property-context pairs from Wikipedia 'Chemistry' corpus

DO	THIS	HERE
	Advances	In design
	Atoms	In state
	Bonds	Of type
	Bonds	Within compounds
	Bubbles	From gases
	Changes	In coefficients
	Chemicals	In petrochemicals
	Elements	With electronegativity
	Fibers	Of glass
	Reactions	At interface
. . . ~4,400 more		

electrochemistry, energy, history of chemistry, inorganic compound, ion, materials science, periodic table, phase, polymer chemistry, redox, thermochemistry.

Purpose-context matrices

The section above illustrates two approaches – combinatorial and extraction-based – to building purpose-context pairs. Here we use the generated purpose-context pairs to demonstrate their conversion into purpose-context matrices. Doing so is important as it helps tie the notions of problem-space and problem-specification to purpose-contexts generated from language. In addition, it enables an ordered view of the problem-space surrounding specific actions. For instance, as shown below, the purpose-context pairs can be ordered by DO to yield problem-space characterization based on the representative action on several objects in various contexts. This is illustrated in Tables 8 and 9 below. We can clearly see the objects across which the action 'absorb' is applicable. In turn, a dimension can be added to map action-object pairs (DO-THIS) with contexts to generate the DO-THIS-HERE matrix for the action 'absorb.'

As indicated above, the team implementing the innovation process to their domain to generate a specific problem-space can use the purpose context mapping shown in the tables above for a given set of contexts of interest. Importantly, domain experts can choose the contextual scale at which to perform the process, thereby controlling the extent of the generated results from the process while not missing key purposes in selected contexts. As visible in the illustration in Table 10, the purpose-context matrix can be evaluated using a

Table 8. Illustrative purposes set for the action 'Absorb'

DO	THIS					
Absorb	Atoms	Bubbles	Chemicals	Energy	Heat	Moisture

Table 9. Illustrative purpose-context pairs for the action 'Absorb'

DO-THIS	HERE				
Absorb atoms	In substrate	Of element	At location	Simultaneously	In series
Absorb bubbles	In reaction	In liquid	From hot gases	At high rates of reaction	During liquefaction
Absorb chemicals	From cloth	Post wash	From soil	Simultaneously	During separation
Absorb energy	In process	From mixture	In reaction	In parallel	Of low orbital electrons
Absorb heat	Of hydration	In reaction	In thermal maging	In temp-regulation fluids	From body
Absorb moisture	At surface	From soils	From food (dehydration)	From air	In process

Table 10. Illustrative Purpose-Context matrix qualitatively analyzed depicting a specific problem-space for the action 'Absorb'

	Context				
Purpose	In substrate	At surface	In reaction	Simultaneously	In series. . .
Absorb bubbles	Medium	High	Medium	High	Low
Absorb chemicals	Low	High	High	High	Low
Absorb energy	Medium	Low	High	Medium	Medium
Absorb heat	Medium	High	High	High	High
Absorb moisture . . .	High	High	Medium	High	High

simple qualitative measure such as the likely importance of the given action on a given property in a given context. While a qualitative method is shown in the illustration, other measures can include technical feasibility, development cost, strategic significance. Complementary to this, the implementation team can apply a capability-context lens to the evaluations in Table 10, which would lead to a strong and well-founded understanding of the capabilities that are potentially applicable across varying contexts that the organization is likely to come across and is therefore, of significance. Capabilities that are applicable across a larger set of potentially significant contexts are more important than others, and the development of such capabilities could then be prioritized. Overall, the purpose-context matrix is a comprehensive mapping of the problem space with a well-differentiated and reduced but specific problem space, and its evaluation leads to a multi-context ordered set of 'to-be-developed' capabilities to solve those well-specified problems.

Importantly, the intent of the example provided above is simply to introduce the purpose-context framework and highlight its application in a product innovation context. The generated purpose-context pairs require human intervention to differentiate between them in a principled way. To this end, automated evaluation would indeed be beneficial, but is beyond the scope of the current paper. Thus, a future research opportunity is the development of software to automatically evaluate the generated purpose-context pairs.

Using purpose-contexts in real world applications

Using purpose-contexts in technical systems

We applied the purpose-context framework to specify novel areas for innovation in Raman spectroscopy. Raman spectroscopy is an analytical technique for the analysis of solids, liquids and gases. In this technique, a monochromatic light source (typically a laser) is directed toward a test specimen and photon-molecule collisions are observed, thereby facilitating chemical analyzes. Because of its versality, Raman spectroscopy is used in numerous applications. However, application purposes and contexts govern the possibility of its use. The combinatorial approach described in the section above was applied to generate purposes and contexts. Purposes were developed based on an understanding of the operation of a typical Raman analysis system, and based on an understanding of the system's potential usage needs, such as the need to *design a sensing device* to *detect macro nutrients* in agricultural soils or to *build* an *affordable and precise device* useful to *predict plant yield* of soils. In summary, purposes were organized into three macro-categories – "detect," "identify" and "quantify." Contexts were developed from an understanding of the constraints. For instance, the device would have to work in *cultivated soils for in-situ application*, for *complex soil mixtures* with a *low concentration of chemicals* and with *limited sampling time*. Three specific contexts were chosen – "in lab," "in industrial process" and "in-situ." The specified problem space was then evaluated by domain experts and intersections of purpose and context were ranked based on their difficulty and opportunity to differentiate from existing solutions. The purpose-context matrix generated by the exercise is shown in Figure 3 and reflects high potential areas for product innovation in Raman spectroscopy.

The purpose-context matrix led to the creation of a research and development program for technical improvements in the system and a series of innovations in Raman spectroscopy, which have since produced multiple research products. Specifically, three awarded US patents (Sinfield and Colic, 2012; Sinfield and Monwuba, 2016, 2018) and two publications (Sinfield *et al.*, 2010; Sinfield *et al.*, 2010), have since then validated the application of the purpose-context framework in problem-specification for the front-end innovation process. It is highly interesting to note that the purpose-context matrix brought

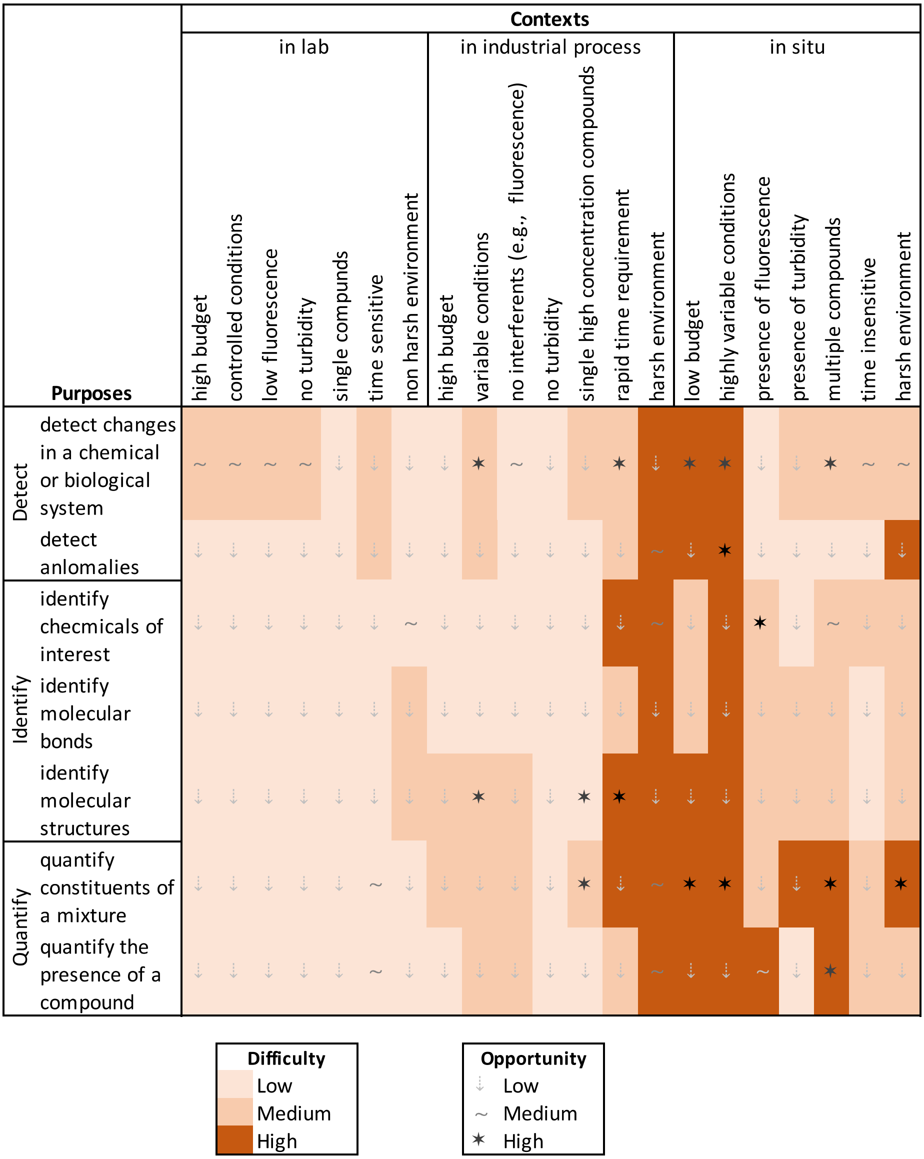

Figure 3. Purpose-contexts framework applied for problem-specification in Raman spectroscopy (Illustrative)

forth several technical gaps with high novelty potential, which were then strategically filled based on difficulty. Evaluation using the purpose-context matrix made it evident that the highest innovation opportunities were in the "quantify" purpose in the "relatively lower-cost" context, which were also the most difficult to achieve. In addition, a high innovation opportunity to "detect" system changes in a "harsh environment" that was relatively less difficult to achieve was identified. Once this was determined, the strategy was to use the in-lab context for nitrogen, phosphorous and potassium detection and quantification in precision agricultural (fertilizers) applications as the entry point. This innovation resulted in US patent 8,325,337 B2, 2012. Next, the learnings were extended to improve ‘identification’ in the high chemical concentration industrial processes for olive oil, which was more difficult to achieve. Finally, the learnings were applied to improve ‘detection’ and ‘identification’ of chlorinated solvents for environmental analysis both in a harsh setting, as well as in the presence of turbidity. This was the most difficult application and was awarded patents US 9.488,582 B2 and US 9,863,881 B2. Therefore, the purpose-context framework not only helped identify gaps for potential innovation, it also helped in developing a research program with an associated development strategy to systematically improve technical innovation in a manner that would reduce risk. The above purpose-context matrix highlighted several innovation opportunities in the Raman spectroscopy domain that continue to remain open opportunities such as the need to “detect chemical and biological system changes” in “industrial processes where rapid time requirements exist” is an innovation frontier. Hence, the purpose-context framework is useful in developing innovation portfolios. Besides technical innovation, the purpose-context framework has been applied to more complex socio-technical challenges as described in the section below.

Using purpose-contexts in socio-technical systems

To understand the potential of using the purpose-context construct to complex problems beyond technical innovation, we explored its applicability to socio-technical grand challenges (Sinfield *et al.*, 2020). In one such case, we examined the challenge faced by a rural village in the Dominican Republic whose residents were accustomed to relying on rainwater for their freshwater consumption needs. A team of scientists had developed and installed a sand filter technical solution in the community, which alone had not succeeded in its objective of converting the village water usage pattern. As part of a larger effort to find a holistic system solution to this issue, we used purpose-contexts to specify components of the problem space related to the socio-technical system at the village level as shown in Figure 4 below. The specified problem space was then evaluated in a workshop where participants ranked the perceived importance of the issues. The rankings were used to identify the specified problems in the socio-technical system, which would need to be addressed to

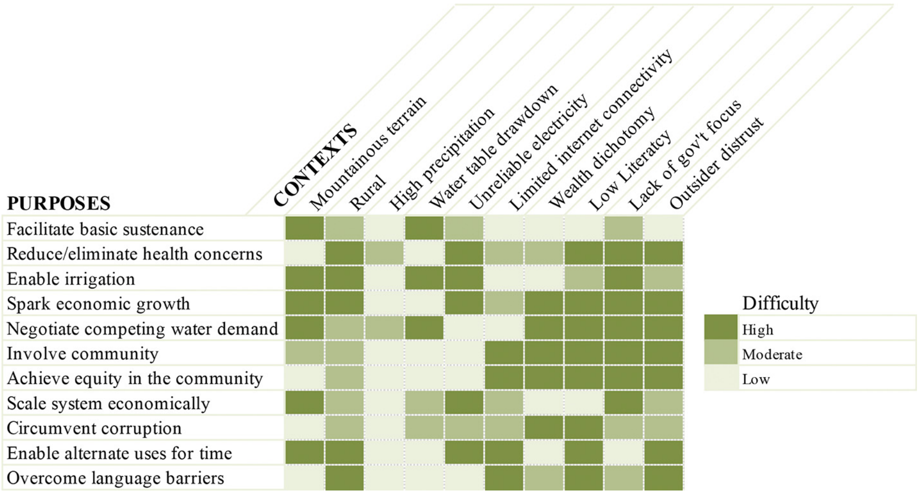

Figure 4.
Purpose-contexts framework applied for problem-specification in potable water adoption in a Caribbean village (illustrative)

engage and encourage the village population to adopt the sand filtering solution. The example presented in the heat map below is illustrative. Note that 280 total specific problems were generated by the purpose-context framework. However, not all of them can be displaced here without making the visual complicated. Hence, this table is only meant to serve as an illustrative example of the output to showcase the application of 'DO-THIS-HERE' to complex challenges, thereby highlighting its usefulness even when the *locus* of innovation is elevated to an organization system level.

Conclusion

We address the process of innovation by introducing a conceptual framework that views innovation as a solution to a problem. We infer problems as purpose-context pairs and represent purposes and contexts as expressed in everyday communication. We also develop links between language as a medium of communication and the proposed framework with a focus on the structural construction of the English language that gives it a systematic grammar and its use in defining purpose-contexts and capability-contexts for the innovation process. In addition, we develop two systematic methods to generate purpose-context pairs by building on the linguistic representations of the framework with the locus of innovation being a product of value. The two methods are bottom-up combinatorial generation of purpose-context pairs that depends on vocabulary (word) selections made by the framework implementers, and top-down information extraction of purpose-context pairs that depends on information selection made by the framework implementers. This is followed by a discussion of the interpretations of the purpose-context pairs and their transformation into purpose-context matrices, which yield well-specified problem spaces for innovators to solve. Furthermore, we discuss the advantages of using the purpose-context framework and its evaluation, which yields an ordered set of to-be-developed capabilities across various contexts.

We demonstrate the practical application of the purpose context framework in technical innovation at the level of product innovation, and socio-technical innovation at the level of system innovation. We explain the purpose-context matrices in both cases (Raman spectroscopy and freshwater system development for villages) and showcase how the framework led to specific problem areas with high opportunities for novelty. Both cases have witnessed real-world innovation impact evidenced by three technology patents awarded by the United States Patent and Trademark Office, two peer-reviewed publications for the technical case, and socio-economic advances for a multi-year on-the-ground applied water system project in the socio-technical case. Finally, the cases also explain the ability and usefulness of the purpose-context framework in developing a strategic approach to innovation pursuit that leads to reduced innovation risk.

In summary, this paper builds on theory in innovation, design and linguistics and converges isolated learnings in the three disciplines to introduce a methodology that can be implemented to make the innovation process more systematic and repeatable in practice. Therefore, methodologically, this paper goes beyond Boyer's (1990) scholarship of integration into a relational scholarship of integration (Bartunek, 2007). We contribute to the literature on innovation by developing a scalable process using foundational elements – data, information and knowledge. This process is systematic and repeatable, and therefore, is an improvement toward a science for innovation.

Note

1. https://en.wikipedia.org/wiki/Chemistry

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