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Advantages and limitations of formal expression

Francis HEYLIGHEN*
Center "Leo Apostel"
Free University of Brussels (VUB)

ABSTRACT. Testing the validity of knowledge requires formal expression of that knowledge. Formality of an expression is defined as the invariance, under changes of context, of the expression's meaning, i.e. the distinction which the expression represents. This encompasses both mathematical formalism and operational determination. The main advantages of formal expression are storability, universal communicability, and testability. They provide a selective edge in the Darwinian competition between ideas. However, formality can never be complete, as the context cannot be eliminated. Primitive terms, observation set-ups, and background conditions are inescapable parts of formal or operational definitions, that all refer to a context beyond the formal system. Heisenberg's Uncertainty Principle and Gödel's Theorem provide special cases of this more universal limitation principle. Context-dependent expressions, on the other hand, have the benefit of being more flexible, intuitive and direct, and putting less strain on memory. It is concluded that formality is not an absolute property, but a context-dependent one: different people will apply different amounts of formality in different situations or for different purposes. Some recent computational and empirical studies of formality and contexts illustrate the emerging scientific investigation of this dependence.

1. Introduction

One of the fundamental questions in philosophy is whether objective knowledge is possible. Epistemology and philosophy of science have concentrated on formulating criteria that would allow us to distinguish objective, "true" knowledge from subjective, unjustified belief. However, an additional problem must be solved before one can start to evaluate the truthfulness of knowledge. Originally, all knowledge exists in the form of ideas or memories, that is to say, patterns of activation in the brain. In order to test the adequacy of that knowledge, it needs to be exteriorised, "brought out into the open", where it can be studied and analysed by a group of observers, without having to depend on the idiosyncratic form and associations it had in the mind of the person who originally "discovered" the piece of knowledge.

That process of exteriorising knowledge, giving it an explicit form with an unambiguous meaning, will be called "formalization". Although some degree of formalization is necessary if one wishes to evaluate the adequacy of knowledge, there are many arguments implying that complete formalization is neither possible nor desirable. In the strongest form, such arguments state that real meaning can only be communicated

* Research Associate FWO (Fund for Scientific Research-Flanders)

through experience, that there are feelings, insights or forms of awareness that cannot be expressed in words or any other explicit, symbolic form (Gendlin, 1962).

Though the need to express knowledge explicitly was felt most strongly in science, twentieth century scientific theories have lent additional credence to such sceptical views on the possibility of formal description. The Heisenberg indeterminacy principle and the theorem of Gödel come most readily to mind as statements expressing fundamental limitations on complete formal representation. Similar arguments have been used in order to deny the possibility of artificial intelligence, where such an intelligence is conceived as a formal representation, in the form of computer programs, of human thought processes (Lucas, 1961; Penrose, 1989).

Rather than dichotomically stating that formalization of thoughts is either possible or not, or either desirable or not, the present paper wants to investigate these questions in a more subtle way. We will introduce a "continuum" of formality, with many different shades in between the extremes of completely formal representations and completely informal ones. It will be argued that the "most adequate" degree of formalization is not absolute, but context-dependent, and that there are situations where informality is to be preferred, as well as situations where the opposite holds. But first, we must define "formality" in a more precise way.

2. A definition of formality

In common parlance "formality" or "formalism" refers to the strict adherence to rules or conventions, where the precise details or forms required by the rules take precedence over their intent. It connotes rigidity and lack of spontaneity, since the rules are supposed to be fixed, not allowing for interpretation or adjustment.

In science and philosophy, "formalism" has a more specific meaning. It denotes a rule-based system of symbolic expressions, where the truth of any expression, generated according to the rules (axioms, definitions, deduction rules), depends only on those rules, and not on any external content or denotation to which the expression would refer. Thus, "form" (the structure of the formal system, as determined by the rules) takes precedence over "content" (that which the system was designed to represent). The typical examples of formal systems are mathematical theories, like topology or set theory. The meaning of a mathematical expression, such as "$n + 1 = 1 + n$", is always the same, whether the number n denotes dollars, people, or chapters in a book.

The definition we want to propose will be more general than the scientific one, yet more precise than the every-day one. We will say that *an expression is "formal" when it has an invariant meaning*. "Expression" denotes an external representation, with a stable, recognisable form, of some internal thought, observation or piece of knowledge. "Invariant" signifies that the meaning of the expression will not change when the same expression is used at different times, in different situations, or by different people, that is to say in different *contexts*.

The most subtle part of the definition is the concept of meaning. Multiple philosophical treatises have been written about the meaning of "meaning", without reaching any form of consensus. The most common interpretation, where the meaning of an expression is equated with the set of outside phenomena that are denoted by, or that satisfy, the expression, appears too limited, as meaning is primarily something that resides "in the mind", rather than in the world of objects. Our definition will explicitly include the mental processes or thoughts of the observer, while trying to maintain the simplicity of this traditional, “denotative” view. The “meaning” of an expression will refer to the *distinction* made by the observer between phenomena for which the expression is considered to be an adequate representation, and those for which it is not.

How that distinction is made is not important for the definition of formality, as long as we assume that some explicit or implicit procedure exists, perhaps only at a subconscious level. We will here not go into further detail about how important or significant a distinction would be for a particular individual, but just assume that it is important enough to be considered.

For example, the concept of “number” is meaningful in our definition if it is possible to recognise some abstract entities as being numbers and distinguish them from other entities that are not. The same applies to concrete objects, represented by expressions, like “stone” or “oak tree”, or to subjective feelings, like “love” or “anger”. For a complex, propositional expression, like “the old man is in love”, the meaning resides in the distinction made between all situations in which the proposition is considered to be true (to be an adequate description), and those in which it is considered to be false. The expression “xpq”, on the other hand, does not have any meaning (at least to me), since I would not in any way be capable to distinguish an “xpq” from a “non-xpq”.

With this conception of meaning our definition of a formal expression reduces to the requirement that the distinction, associated with the expression, be invariant. That means that the same entity which I recognised as a “number” would still be recognised as such at a later instant, by another person, or in another setting. Additionally, the entity that was distinguished as a “non-number” should keep that status in different contexts.

3. “Formal” and “operational” expressions in science

We already mentioned the fundamental role of formalism in mathematical models. Since the rules for deriving theorems are explicitly given, any mathematician in any situation can in principle check whether a proposition is true or not for the given values of its variables.

In the empirical sciences, formality has a somewhat different appearance. The rules that allow one to distinguish between a situation adequately represented by an expression, and a situation for which the expression is inadequate, are here not an inherent part of the formal system. They rather refer to some “reality” outside the system of expressions, and express a way of testing in how far that reality conforms to the expression. Such rules are called *operational*, since they describe experimental procedures, or operations, to be performed on the outside phenomena.

For example, in order to operationally determine the meaning of the expression “has a weight of one kilogram”, you might perform the following operation: put an object on a balance; wait until the balance stabilises at a particular value; if that value is 1, then the object weighs one kilogram. Assuming that all balances are calibrated in the same way, you now have determined the meaning of the expression in an invariant way. If a theory would predict that a certain type of object has a weight of one kilogram, all scientists in every part of the world would now be able to test that theory, using the above rule.

Since operational rules differ from formal-mathematical rules, which do not refer to any outside phenomenon, one conventionally distinguishes between ‘formalising’ and ‘operationalising’ a theory. In the present approach, both ‘formally’ and ‘operationally’ determined expressions are considered to have an invariant meaning, and, hence, fall under the more inclusive category of “formal descriptions”. Unfortunately, no word exists that encompasses both the concepts of “formal” and of “operational” in their restricted, scientific senses. Therefore we had to use the word “formal” in an extended sense, creating the danger of confusion or misinterpretation.

Still, the present, inclusive, use of the term may be motivated by the fact that the distinction between “formal” and “operational” in science is less sharp than it might seem. Indeed, it is possible to conceive of intermediate cases, where a rule determining how to make distinctions is neither really formal nor operational. In traditional formalisms, the checking of the truth of an expression is supposed to happen purely in the mind of a mathematician, whose thought processes follow the established rules. However, when the formal system and its associated rules become too complicated, no human mathematician will be able to check the validity of all expressions. In such cases, more and more often one uses computers that apply combinations of rules in a much faster and reliable way than any human could. The results of such computations are often as surprising as real experiments in the outside world, and this type of investigation of the possible consequences of formal models is often viewed as a ‘simulation’ of such an experiment. In the end, the computer becomes a tool or apparatus that substitutes for the human mind, in a way not very different from the way a balance substitutes for a human arm. The difference between a ‘formal’ and an ‘operational’ test is then not much more than a difference between instruments used.

4. Fuzziness and context-dependence

Given our definition of formality, we can start to explore the domain of non-formal expressions. First we must remark that the definition is not of the “all-or-none” type: expressions can have a meaning that is more or less invariant or variable. That leads to a view where formality comes in degrees.

An extreme type of non-formal expression would be an expression that does not have any meaning at all, like “xpq”. An intermediate type would only have a vague or fuzzy meaning, signifying that there is not a clear procedure for making a distinction. The same phenomenon might sometimes be distinguished as a “rst”, sometimes not, without any way of predicting what the result would be. This is an example of an essentially statistical or probabilistic type of uncertainty.

Fuzzy logic or fuzzy set theory is a mathematical approach that tries to capture such inherently vague expressions (Klir & Folger, 1987). For example, stating that there are “many” people in a building is a fuzzy expression. Are 12 people considered to be “many”, or should we rather expect to see at least 200 of them? In fuzzy set theory the vagueness of an expression is represented by a probabilistic (or possibilistic) distribution of possibilities, where 200 is considered to be more likely to be distinguished as “many” than 12. Both belong to the class denoted by “many”, albeit to a different degree.

Another type of non-formality is the one where an expression does have a clear meaning, but where that meaning is variable. Consider a simple pronoun, like “he” or “I”. In ordinary speech, it is in general perfectly clear to the speaker and to the audience which person should be distinguished as “he”. However, the same expression used at another time, or by another speaker, will in general refer to a completely different person. Such expressions, where the meaning is different in different circumstances, will be called *context-dependent*. The specific conditions, external to the expression itself, such as speaker, audience, situation, time, etc., which determine the meaning of the expression, will be called the *context* of the expression. Context-dependence can be viewed as the real opposite of formality, whereas fuzziness would be rather the opposite of preciseness.

In philosophy, context-dependent expressions are usually called *indexical* (Bar-Hillel, 1954; Barnes & Law, 1976). Linguists usually speak about *deixis* (see e.g. Levelt, 1989) if an expression refers to a concrete part of the spatio-temporal context, and about *implicature* (Grice, 1975) if it refers to more abstract background assumptions. Examples of deixis can be found in simple expressions like "I", "his", "them", which must be connected to a particular person, "here", "over there", "upstairs" which must be attached to a particular place, and "before", "now", "tomorrow", which must be linked to a particular time. An example of implicature is the following: if a person entering a room with an open window through which wind is blowing says "It is cold here", the likely implicature is "I would like the window to be closed". Though that message was not uttered literally, it is easily inferred from the background knowledge that heated rooms become warmer when windows are closed, and that people prefer not to feel cold.

It must be noted that a fuzzy expression, such as “many”, can also be context-dependent. This context-dependence is normally not taken into account in fuzzy set theory, which is a traditional formal theory. When we speak about a family with “many” children, we might mean as little as 4 or 5. On the other hand, when we say that “many” people live in the capital, the number expected would be of the order of millions. In this view, “many” would be interpreted as “more than the normal amount”, where what is “normal” depends on the context. Yet, in neither case we can exactly determine which number is meant, unlike the case of a pronoun like “he”, where the person referred to is normally unambiguous. Similarly, the context-dependent word "here" is also fuzzy, since even if we know what place the word "here" refers to, it is difficult to determine a clear boundary between "here" and "there".

We must further distinguish fuzzy or context-dependent expressions from *general* ones. For example, an expression denoting a very broad or abstract category, like “material objects” or “human beings”, might appear vague because many different types of entities fall under it. Yet that does not imply that its meaning is either imprecise or variable. For example, a “child” denotes a specific subclass of “human being”, yet is much more fuzzily defined than the superclass. Normally, no one hesitates in distinguishing a “human being” from an “animal”, “plant” or “mineral”, yet it is not at all clear when a “human being” stops being a “child” and becomes an “adult”. Similarly, a “fool”, denoting a subclass of “human being”, may have a very particular meaning in a certain context, but only in that context. The same person may be referred to as a “fool” by one individual , and as a “serious person” by another individual, or even by the same individual in a different situation.

5. Advantages of formality

Formal expressions, the way we have defined them, have a number of clear advantages over context-dependent ones. These unambiguous benefits explain why science insists so much on formalization of theories and hypotheses.

Perhaps the most obvious advantage is that formal expression allow knowledge to be stored in the long term. Indeed, since the meaning of a formal expression is by definition independent of time, that meaning will remain for future uses. The longer we desire our expressions to remain meaningful, the more formal we should try to make them. That is one of the reasons why written language tends to be more formal than spoken language (Dewaele, 1992).

The second advantage is the capacity for universal communication. If you communicate with only one person you will basically share the same context, and so the meaning of your expressions may be clear without any need for universal rules of interpretation. However, if you want your message to get across a large variety of different people, who all have different backgrounds, attitudes or situations, it is better to express yourself in a way which is as much as possible independent of a particular context. That is the situation of the scientist or of the philosopher, who tries to formulate universal principles, understandable by and applicable to people of all ages, classes or cultures.

A third advantage is the testability of formalised knowledge. Since the context of a test, checking the validity of a expression, will never be exactly the same as the context in which the original proposition was made, the result of the test may have little to do with the original proposition, unless the proposition was formulated in such a way as to be context-independent. It is this testability which motivates the strict requirements of formality in the formulation of scientific theories, as well in the mathematical as in the empirical sciences.

A combination of the previous advantages leads to what is perhaps the most important benefit of all: formal expression makes it easier to accumulate and improve knowledge. Testability implies that it is possible to select good descriptions and reject bad ones. Storability implies that the good ones can be maintained. Universality means that knowledge developed by different people in different places can be exchanged and collected, so that a growing pool of well-tested knowledge becomes available.

It is no surprise then that the scientific method, which essentially relies on the use of formal methods for description, has been so immensely successful in developing new theories and technologies. More generally, the whole Western culture, which engendered the scientific method, benefits from this emphasis on formal descriptions. In the Darwinian competition between cultures or systems of ideas (“memes”, see Moritz, 1990; Blackmore, 1999), formal expression is a definite advantage, that makes survival and reproduction of the idea it carries much more likely. Thus, formality is one of the selection criteria that determine the fitness of a "meme" (Heylighen, 1997, 1998). The present dominance of scientific and technological culture over more traditional cultures can, hence, be interpreted, not as the result of suppression of rival systems of ideas, but as the natural selection of those ideas that are expressed in a more robust manner.

This does not mean that scientific, or formally expressed, ideas are intrinsically superior: it is possible to have a very good idea without formal expression; however, the lack of storability and communicability signifies that the idea will be easily misinterpreted, overlooked or forgotten, whereas a less good, but clearly expressed idea, will be taken much more seriously.

6. Limitations on formal expression

In view of the above advantages, it would seem that in a Darwinian evolution of knowledge it might not take long before all knowledge of any persisting value would be expressed formally. Yet, all scientific researchers know that in practice it is very difficult to express ideas in a formal way. Moreover, it can be shown that complete formalization is impossible in principle. The reason for these restrictions is that *the context cannot be* *eliminated*. In order to understand this better we must analyse in more detail how an expression can be made formal, i.e. how the distinction it represents can be determined in an invariant way.

6.1. The infinite regress of definitions

The most primitive way to establish the meaning of an expression is by *ostension,* by pointing towards some present phenomenon and saying “that thing there”. Normally, this is sufficient to make sure that your audience understands what you mean. However, the meaning was established purely by reference to an entity outside the realm of linguistic expressions. When the context is changed, the entity will in general no longer be present, and the expression “that thing” will lose its meaning.

In order to maintain the meaning even when the phenomenon referred to is absent, you might *define* the phenomenon, i.e. formulate an expression that unambiguously states how to distinguish it from other phenomena that you might encounter. For example, you might replace “that thing” by “the sculpture in front of the building at 34 East 22nd Street, New York”. This expression should make it possible to identify the phenomenon even for people who have not been in New York. What a definition does, is make the context enter the linguistic description, so that it loses its status of “context”.

The problem is that the elimination of context is only provisional. The above definition would not be in any way useful if you do not know where New York is. Again, you would need somebody to indicate to you the position of New York on a map. You might circumvent the problem by defining the position of New York in terms of its longitude and latitude, but these only make sense if you know the references on the basis of which they are determined, that is to say the equator and the meridian of Greenwich. Perhaps you might explain to someone where Greenwich lies by giving its distance from New York, but that would only bring you back to where you started from.

The general problem is that you can only define expressions by means of other expressions which need to be defined themselves. If you continue long enough defining each newly introduced term and all terms in its definition, you will discover that some of the earlier defined terms reappear as terms in the further definition, like the term “New York” in the example above. Such a ‘bootstrapping’ cannot be avoided, since there is only a finite number of terms available (e.g. all words in a dictionary), and so you must come back to the place you left from after a finite number of steps, starting over the whole carrousel of definitions. (Note that one might use the bootstrapping principle itself as foundation for a higher-order formalism, that can take into account different degrees of context-dependence, see Heylighen, 1992, 1999a. This, however, does not solve the problem of formalizing an individual expression.)

6.2. Primitive terms refer to the context

The only way to evade such an infinite regress is to stop with some terms that are considered *primitive*, in the sense that their meaning is assumed to be given. In the empirical sciences, primitive terms are ostensive. For example, in physics you might define “1 kilogram” as “the weight of 1 liter of water at 4 degrees Celsius”, and “1 liter” as “the volume of a cube with a side of 0.1 meter”, but finally you would have to define “1 meter” by reference to a phenomenon outside your linguistic representation, namely as the length of the platinum bar that is kept in the Paris bureau of standards.

In mathematical formalisms, primitive terms are left undefined. Their meaning is supposed to be ‘implicitly’ defined by the rules (axioms) that they obey. That means that an entity that does not obey the axioms a given primitive term is supposed to obey is distinguished from those that do. A mathematical formalism is *closed*: its terms only refer to each other, not to any entity outside the formal system. But the problem appears when we want to use a mathematical expression as a representation of some concrete phenomenon. Nothing within the formalism tells you how to do this, unlike operational systems where there are rules telling you how to determine the weight of a concrete object.

Suppose you have a formalism for number theory, with primitive terms such as “1”, “2”, and “+”. One of your rules might state that “1 + 1 = 2”. Now you can use this rule to conclude that if you add one apple to another apple you have two apples. You have mapped apples to units (“1”) in your system and adding apples to the operation “+”. This seems straightforward. However, assume that you add one drop of water to another drop of water. You would still have only one drop of water, albeit a bigger one. So we must conclude that the mapping of concrete phenomena onto mathematical expressions is not at all unambiguous, and that you need some knowledge about the context (e.g. that apples have stable boundaries but that drops of liquid do not) in order to distinguish adequate mappings from inadequate ones.

Another example can be found in geometry. There are different, inequivalent formal systems for geometry, including Euclidean and non-Euclidean ones. Which one you should use in order to represent the geometry of physical space, will depend on the context: for most every-day purposes, Euclidean geometry will be adequate, but if you are studying gravitational fields in general relativity theory, you will need a non-Euclidean one.

6.3. Intrinsic limitation principles

Even if we stay within the closed system of axioms and rules, and forget about the mapping of concrete events, formal systems retain a basic ambiguity. This was shown by the famous theorem of Gödel (see e.g. Zwick, 1978). The theorem states that in any formalism that encompasses number theory (which is perhaps the most basic formalism of mathematics), there are expressions of which the truth or falsity cannot be proven within the formalism itself. In other words, the formal system does not propose any procedure for distinguishing between the cases where a certain expression is valid or not. According to our definition of formality, such expressions are not formal. In fact, the undecidable expression proposed by Gödel can be shown to be true on the basis of arguments from outside the formalism, in our terminology by reference to the context. But that context cannot be encompassed by the formalism: though the formalism can be enriched by incorporating additional rules, there will always remain expressions whose truth is undecidable within the formalism.

The general principle underlying these limitations was called the *linguistic complementarity* by Löfgren (1988, 1991). It states that *in no language* (i.e. a system for generating expressions with a specific meaning) *can the process of interpretation of the expressions be completely described within the language itself*. In other words, the procedure for determining the meaning of expressions must involve entities from outside the language, i.e. from what we have called the context. The reason is simply that the terms of a language are finite and changeless, whereas their possible interpretations are infinite and changing.

In the empirical sciences, the principle is exemplified by the Heisenberg Uncertainty Principle (or, in another version, Bohr’s complementarity principle), which describes the observation process in quantum mechanics. Simply put, it states that any observation perturbs the system being observed in an uncontrollable and unpredictable way. Since not all properties of a system can be observed at once, the necessary observation set-ups being mutually incompatible, the determination of one property by observation will necessarily create an uncertainty in the determination of another, incompatible (or ‘complementary’) property.

The observation set-up can be viewed as an instrument for distinguishing whether a physical system has a certain property, represented by an expression, or not. The principle states that such an operational determination can never determine the validity of all possible expressions (properties) describing a physical system. The reason is that the apparatus itself has some unknown (not included in the description) properties, that will influence the result of the determination by, however slightly, changing the state of the system being measured. Those properties belong to the context, and cannot be eliminated. Measuring them with the help of another observation apparatus would only bring in additional unknown perturbations, again leading to an infinite regress (Heylighen, 1990).

The same limitation appears in the social sciences. Social scientists are well-acquainted with the "observer effect", the influence of the researcher on the person or group she investigates. The answers people give to a questionnaire often depend on how the questions are formulated and who asks the questions. For example, people are more likely to agree with a friendly and attractive investigator, or to answer a particular question in such a way that the answer seems consistent with their previous answers, even though they might have answered the same question differently if it had been the first one on the list. This observer effect is difficult to determine, and can never be completely eliminated.

6.4. ‘Normal conditions’ as implicit contexts

The context does not only enter operational procedures in the form of microscopic perturbations due to the observation apparatus. When we proposed to operationally define “weighs 1 kilogram” with the help of a balance, we neglected a number of more visible aspects. Every time someone puts an object on a balance, something about the situation will be different: perhaps the balance, or the experimenter, the geographical location, the weather, the size of the room, etc. It is obvious that some of these variables will influence the result of the operation. For example, using a non-calibrated balance will skew the result. Similarly the result will be different if the weighing is done on the moon, where gravity is one sixth of earth gravity. On the other hand, the weather or the colour of the experimenter’s tie should normally not influence the outcome.

It is impossible to enumerate the infinity of factors that might or might not influence the result when defining the operational procedure. Some well-known sources of errors may be explicitly included in the statement of procedure, like calibration, and the fact that the experimenter should not lift or push down the object on the balance. All other factors will be assumed either to have no effect (weather, ties, ...), or to have normal, ‘default’ values (gravity, internal mechanism of the balance, ...).

But the set of all ‘normal conditions’ in fact determines an implicit context for the procedure. Changing that context (e.g. weighing an object on the moon or under water) will change the result. We can only conclude that underneath each operational definition a specific context is hidden, albeit that the context under which its meaning is invariant (normal gravity, ...) tends to be much broader, or less likely to be changed, than the context of most every-day expressions that are not operationally defined. Hence, the meaning of an operationally defined expression will be less variable, but never completely invariant.

6.5. Causal factors determining context-dependence

It is a common observation that some domains of scientific inquiry lend themselves more easily to formalization or operationalization than others. For example, models in physics are in general much more precise and unambiguous than models in sociology. In general, the models in the natural sciences tend to be more universal, i.e. independent of place, time, and observer, than the models in the social sciences and humanities. This may be explained by analysing the structure of causality in their respective domains.

The principle of causality states that every unique state of the universe S_i produces another unique state of the universe S_f, $S_i \rightarrow S_f$. This may be called "microscopic" causality since it assumes that cause S_i and effect S_f are known in every possible detail for all parts of the universe, however small. Although this principle may be fundamentally true, it is useless in practice, since, unlike Laplace's imaginary demon, we can never know the precise states S_i and S_f. To make reliable predictions, we must use *macroscopic causality*, the principle that a known, observable cause K_i produces a known effect K_f. This can be derived from the microscopic causality principle if we split up the state of the universe into a known component K and the set of remaining, unknown background factors, B:

$S_i = K_i + B_i \rightarrow S_f = K_f + B_f$.

If we can now eliminate the background factor B, we get a macroscopic prediction: $K_i \rightarrow K_f$. This model of causality is similar to our model of expression, where an expression E together with a context C determine an interpretation I: $E + C_i \rightarrow I + C_f$. It is also analogous to our model of operational determination or measurement, where property and measurement context together determine measurement result: $P + C_i \rightarrow R + C_f$. This means that the formal expression of a causal law (i.e. the statement of the universal relation between two distinguished phenomena independently of the specific context under which those phenomena are to be distinguished) will only be possible if we can eliminate the background factor B from the corresponding causal relation.

There are at least two cases in which we can ignore the unknown background factor. The first case is when K, the factor we are interested in, is not affected by B. Apart from the rather unrealistic situation where the phenomenon we observe is completely isolated from the rest of the universe, this will usually be the case when K is stable and able to resist different kinds of perturbations. For example, a heavy desk is intrinsically stable and will not be affected by wind, vibrations or random distributions of air molecules. Therefore, we can predict that the position of the desk will only be affected by a push strong enough for us to observe it. We do not need to consider undetectable background effects. A coin standing on its edge, on the other hand, is in a definitely unstable state, which will quickly disappear. Because of this intrinsic instability, it is sensitive to the slightest perturbations, and therefore macroscopic causality will not help us to predict its trajectory. The coin standing on its edge is a chaotic system, which does not allow for deterministic models that only contain observable factors.

The second case in which we can forget about the background is when that background itself is stable. If the background conditions are always the same, then we do not need to know how they affect the system K in which we are interested. We just need to observe a few instances of the phenomenon and derive a general rule. For example, by watching apples falling from a tree we may derive the rule that heavy objects fall to the ground. If we observe carefully, we may even derive the precise acceleration with which they fall. However, we do not need to know that what determined their fall is an invisible force called "gravity". Gravity only becomes relevant for predictions when it varies. For example, the gravity on the Earth is different from the gravity on the Moon or in space, and therefore objects will fall differently in those different places. Gravity can be ignored on the surface of the Earth because it is invariant: it is everywhere the same and it never changes.

Each time we predict that a heavy object will fall to the ground, we unconsciously make a host of assumptions about the background conditions. We assume that gravity will remain constant. We assume that there won't be a tornado sucking in objects and blowing them high up in the sky. We assume that there won't be a magnetic field counteracting the force of gravity. We assume that the medium around the object (normally air) is lighter than the object itself. We assume that the object is not self-propelled, like a helicopter or a fly. We assume that the object will not suddenly change its physical structure and become lighter than the air. We assume that the laws of physics will remain the same...

There are an infinite number of such assumptions that we need to make if we want to justify our prediction. Yet, in practice, we can forget about all these conditions by simple assuming that the situation is *normal*. "Normal" means fit, stable, or "the way things usually are". If things were constantly changing, so that we could not trust whether gravity would still be there the next we time we looked, then predictions would be impossible, and macroscopic causality would not exist. It is because unstable situations tend to disappear spontaneously that in many cases we can ignore the background factor B, and focus on K. In other words, stability is a product of natural selection (cf. Heylighen, 1994, 1999b), and is therefore common enough to make macroscopic causality practically useful.

The stability of background conditions explains why formalization is easier in physics than in the social sciences. When physicists express physical laws, such as "massive objects in a gravitational field fall", or "opposite electric charges attract", they are much more categorical than social scientists expressing the laws of their domain. Social scientists tend to accompany any rule or prediction with the phrase "ceteris paribus", which is Latin for "all other things being equal".

For example, a psychologist might predict that if you ask people whether they would prefer going to a wild party or staying at home to read a good book, then the extroverted will prefer the party while the introverted will prefer the book. Yet, we all know that predicting people's behavior is not that simple. Perhaps the extrovert would be tired and prefer to stay at home, while the introvert would just have been studying for exams during the last couple of weeks and be ready for some action. Or the introvert might hope to run into an old friend at the party, while the extrovert would be afraid to meet an ex-spouse. We will never know all the factors that influence the decision. That is why such a prediction needs a qualification: *all others things being equal*, an introvert will prefer the book, while an extrovert will prefer the party.

Of course, we will never find two people whose situations are completely equal except for their degree of introversion. Therefore, the psychologists' prediction is only statistically valid: *on average*, introverts are more likely to prefer the book. Social science predictions are less reliable because the background factors in social situations are much more variable than the background factors in physical situations. The social domain is still in full evolution, while in the physical domain, things have had plenty of time to settle down and reach stable configurations. This has not always been the case, though: shortly after the Big Bang, the physical domain of particles and forces was in full upheaval and the "laws of Nature" that we rely on now would have been essentially useless as tools for making predictions.

7. Advantages of context-dependence

Apart from the fact that the inherent limitations on formal expression force a certain reliance on the context upon us, context-dependent ways of expressing thoughts have some benefits of their own.

7.1. Context determines a memory neighbourhood

Formal descriptions require an exact memory of all expressions and rules involved in the meaning of the present description, and, moreover, a memory of all intermediate steps in the deduction of the meaning of new expressions on the basis of existing ones. Human memory is not very well-suited for meeting that requirement, as we already suggested in the paragraph on computers replacing mathematicians. Short term memory has a very limited capacity, whereas long term memory is *associative* (Heylighen, 1991): knowledge is remembered only insofar as it has some association with the part of memory that is currently activated (by perception or thought). This implies that at each moment only a relatively small “neighbourhood” of recently activated or associated memories, determining a mental state, will be available for interpreting expressions.

The content of that *memory neighbourhood* is determined largely by the context. It includes perceptions of the most salient features of the situation: speaker, audience, setting. In addition it contains a short term memory of the things that have been expressed (said, read) before. But not much will remain of things said more than a few minutes ago. Finally, it includes long term memories that have been activated because they are somehow associated to the former things in memory. For example, if someone uses the word “moon”, that might conjure up the image of a romantic walk you once had in the moonlight, or, alternatively, a photograph you saw of the first man setting foot on the moon surface.

All these things are quite variable and depend strongly on the person and his or her memories, the situation, and the order in which different things have been mentioned. Yet, they will strongly determine the way an expression is interpreted. Without remembering, no meaning, and without selective activation of certain neural patterns, no remembering. By activating the right patterns in the right order, a good transfer of meaning may occur. That is what the context can be used for.

With formal descriptions, on the other hand, there is little chance that the meaning would be spontaneously transferred. In order to interpret mathematical expressions you need, in addition to a detailed memory of all background rules defining the formalism, a strong discipline that will keep your attention focused on the relevant expressions, instead of letting it wander off following all thoughts and associations that are spontaneously evoked by the context. That explains why most people find mathematics, physics and related formal domains much more difficult to study and understand than associative, context-dependent domains such as literature or art.

7.2. Creating involvement

It is in the latter domains that the power of reference to the context becomes most clear. In novels or stories, the first step is the creation of a setting, on the background of which the narrative takes place. Most parts of the setting are not strictly necessary to understand the following story, but they serve to activate the relevant parts of associative memory, thus making it easier for the reader to discover meaning in the following descriptions. If the context is similar to a context the reader has experienced before, the reader will also feel personally involved, and be more motivated to comprehend the message. The narrative itself functions as a continuous rebuilding of the context, so that each event can be interpreted in the light of the immediately foregoing events. This continuous, but not necessarily “logical”, flow of description makes it easier for the reader to stay focused, in contrast to a formal model that consists of mostly discrete, separate propositions without any fixed ordering.

Similar techniques of creating a context in order to aid understanding are used in journalism and the popularisation of scientific knowledge. The aspect of personal involvement is often called “human interest”. For example, instead of using the formal proposition “Statistics show 24% more crimes reported to the police in 1992, as compared to 1991, in the city of Los Angeles”, a journalist would rather set up a context, involving some person to whom the reader can relate, in order to express the same idea: “Sam Smith, sergeant for the Los Angeles police since ten years, married to Helen, with two kids, Josh (4) and Jeff (2), seems worried: ‘We have been called much more often on the streets for criminal offences lately. Among the LA cops, there is a feeling that crime is on the rise’.” Insofar as crime evolution is concerned, the second quote is probably less informative, and certainly less precise, than the first one. Yet, one might assume that the background information about the policeman’s family and feelings, which is irrelevant to the formal meaning of the message, would help to create personal involvement and activate the appropriate associations of ‘increasing danger to loved ones’ which is an underlying subject of the message.

In many cases, though, this style of reporting will tend to obscure the objective information contained in the message, by burying it in a heap of irrelevant background information about informants’ family and living conditions. The power, and at the same time the danger, of context-creating ways of expression, are illustrated even more strongly by different forms of persuasion and rhetoric, as used e.g. in advertising and selling. Most ads, especially those on TV, contain remarkably little information about the product they try to sell. They rather attempt to activate positive associations by showing the product in a context that is considered very pleasant, e.g. beautiful young people bathing and playing on the beach of a tropical island.

Especially salesmen are very skilful in gradually building up a context where all positive features of their product are emphasised, while all possible negative aspects (like prize), are pushed to the background. After a sufficiently long session of persuasion the activated memory neighbourhood or mind set of the prospective customer will be such that there seems no alternative left but buying. The same product, presented only with a formal list of its advantages and disadvantages, would certainly appear much less attractive.

Although the setting up of a context in this way can be dangerously misleading, it is also of immense use in conveying any complex message to an uninitiated public. Scientists who wish to convey their ideas to students or colleagues would do well to study the underlying psychology of explanation and persuasion. Many of the greatest scientists, including Darwin and Einstein, have shown how complex, novel ideas can be presented in such a way that readers are gently led into the subject, so that at the end the abstract principles almost emerge naturally from the carefully prepared context.

7.3. Flexibility of context-reference

A more universally positive feature of reference to the context, is that it allows us to formulate meanings for which no formal expression exists as yet. By using eminently context-dependent expressions like "it" or "that thing there", it is possible to refer to the most unusual phenomena. Indeed, formal expressions by definition try to capture invariant distinctions, but some distinctions are intrinsically variable (Heylighen, 1990). Moreover, the number of terms in a formal system is necessarily finite, and their combinations (part of which are expressions) are at most denumerable, whereas the number of potential distinctions is continuously infinite. So, there will always be distinctions to be made for which no formal expression exists. The number of possible contexts, on the other hand, is infinite, and each context can be continuously varied by changing its features.

The problem remains, however, that you can never be certain that the context you have set up will carry the intended meaning to your audience, since there are no consensual rules on how to interpret contexts. The meaning ultimately depends on the whole experience that the person has had, and that is stored in his or her brain in the form of associations. The only way to communicate eminently subjective phenomena, such as a romantic feeling, a drug-induced hallucination, or a mystical experience, is by making your audience undergo a similar experience. The best you can do is try to recreate the major elements of the context that engendered the experience: moonlight and music, LSD, or prolonged meditation. But even if you succeed in perfectly recreating the complete external context, you can never control the way this context influences the mental state of your subject. The more similar the background, personality and experience of the subject, the more similar his or her interpretation, but no two persons will ever be identical.

We may conclude that the more language becomes context-dependent, the more intuitive, direct and flexible, but the less reliable it becomes as an instrument to transfer or store meaning. In the limit of totally context-dependent expressions (i.e. that have no meaning on their own), language or description becomes just behaviour.

8. Formalizing formality

8.1. The continuum of formality

We have shown that the context cannot be completely eliminated in the definition of the meaning of expressions. In certain domains, for example mathematics or physics, it is possible to refer to a context that is so broad and stable that, for all practical purposes, it can be assumed to be universal or invariant, and thus can be ignored. In other cases, like in the description of personal feelings, the phenomenon to be expressed is so unstable and subjective, that it can only be understood by reference to one very specific and variable context.

Given these external constraints on the phenomena being expressed, we can still choose how much context we want to involve in the communication, taking into account the different advantages and disadvantages of formality. If we want our descriptions to be unambiguous, persistent and testable, we will reduce the role of the context. On the other hand, if we prefer to be flexible and direct, we will avoid formality. Depending on our intentions and the overall stability of the domain to be described, it should be possible to determine an optimal level of formality: enough, but not too much.

We can thus conceive of a continuum of formality. On the most formal extreme we would find mathematics and logic, followed by the ‘hard sciences’, physics, astronomy and chemistry. Then, we would have the biomedical sciences, where formality is still very important, but more difficult to achieve, given the complexity and variability of the systems being studied. Following that come the ‘soft sciences’, psychology, sociology, and the humanities, characterised by even more variable subject domains. Outside the domain of science, formality is still very much needed in law, and to a less degree in diplomacy and politics, where it is important that rules and agreements should not be misunderstood. Everyday written or otherwise broadcasted information, like that in newsreels or magazines, forms a next level of lower formality. General conversation becomes more and more informal, when going from polite exchanges between strangers to talks between colleagues, friends or family members. The extreme of informality might well be found among identical twins that were raised together: when so many things in the context are shared, the need for formal expression becomes minimal. People in such a close relationship often do not even need to say anything in order to be understood, and are found to develop ‘private’ languages, that only they understand.

An important new research domain seems to be emerging which studies these variations in formality and context-dependence in a more formal way. This can be seen as a metatheoretical or “second order” approach to the issue of formalization in science: using formal and operational methods in order to studies the properties of formalization. As the results are as yet only preliminary, we will here only outline some illustrative examples.

8.2. Formalizing context

First, there are a number computational approaches, that try to capture the concept of “context” in a formal way, in order to build a system with artificial intelligence (AI) (AAAI, 1997; Akman & Surav, 1996). As we noted, one of the fundamental criticisms of the feasibility of AI is that the whole of human experience can never be captured in a formal system. More practically, this is known in AI as the “frame problem”: any system trying to act in the real world must carefully select which aspects or features of its situation (frame of reference) it should take into account; otherwise it may either overlook essential problems, or get bogged down in interminable chains of inferences about irrelevant details (van Brakel, 1992). Simply put, although formal representation of the problem requires that one incorporate part of the context in the description, one must be selective. Including too much of the context makes the representation too complex to cope with, even for a computer, since very many distinct alternatives will have to be considered when making decisions. On the other hand, sticking with a fixed, limited context, may be inappropriate for a new problem.

Therefore one needs the ability to easily shift contexts, explicitly including certain parts of a context, while leaving other parts temporarily out of the main problem representation. New questions, new data or new insights will then require the formal inclusion of different aspects of the problem, and hence the creation of another context. In such representational systems nothing is rigid, yet the adoption of formal rules for shifting contexts provides a stable framework for the manipulation of meaning. For example, Ezhkova's (1989, 1992, 1993) formalism assumes a collection of contexts and data represented in the background ('long term memory') in the computer system, out of which one or several contexts can be selectively constructed or actualised (put in 'short term memory'), in order to solve a particular problem.

Although the formal representation of different contexts makes the system more flexible, it still remains closed: aspects of the environment that have not been formally represented at some level inside the system remain forever out of reach (Heylighen, 1999a). One way to get out of this impasse is to provide the system with the capacity to autonomously learn from its environment, but this requires sophisticated sensors, effectors, and algorithms to make sense out of the correlations between the various perceptions and actions. An as yet more practical approach assumes that all knowledge about the context ultimately resides with the human user of computer program, but that the computer can help the user to selectively and partially formalize that part of the context that is needed for the problem at hand (Heylighen, 1991). Thus, human and computer working together may constantly expand and revise the formal representation depending on the changes in the context (Heylighen, 1999a).

The indeterminacy in quantum mechanics has inspired a different approach to the formalization of context-dependence. Aerts (1998) has shown that the non-classical probability structure of quantum mechanics can be explained by assuming that we lack information about the state of the observation apparatus. The degree to which the observation result depends on the state of the apparatus, and not just on the state of the system being observed, determines the degree of uncertainty about the result. This dependence on the measurement context may be called *contextuality*. Aerts has introduced a parameter, "epsilon", that measures the degree of contextuality of the result. In traditional quantum mechanics, epsilon is fixed, but in other domains, it can vary. Aerts and Aerts (1994) have begun to develop an "interactive statistics", which generalizes the measurement model from quantum mechanics to social sciences. This approach makes it possible to determine the degree of contextuality on the basis of the statistical pattern of answers to a series of questions. Questions for which the answer is independent of the context of other questions will produce a pattern different from questions for which the answer is influenced by the context.

8.3. Linguistic measurement of formality

Formality can also be studied in an empirical way, by observing the way people use natural language. From the previous analysis it follows that different people will express themselves with different degrees of formality in different circumstances. In order to analyse this, you first need to be able to *measure* the formality of every-day language in a simple, operational way. One approach to develop such a measure is to look at the differences between language produced in situations where there are clear requirements of formality, like in written dissertations or oral examinations, and those produced more informally, like in spontaneous conversations.

In a study of students using French as a second language (Dewaele, 1996), a statistical factor analysis on the basis of the numbers of words belonging to different classes (nouns, verbs, prepositions, etc.), revealed one major factor that strongly correlated with the formal requirements of the situation. The factor, which was called "*explicitness*", varied positively with the number used of *nouns* and words that normally surround nouns, i.e. *adjectives, articles* and *prepositions*, and negatively with the number of *verbs*, *pronouns*, *adverbs* and *interjections*. These findings can be easily interpreted in the present conceptual framework. Nouns ("woman", "tree", "peace", etc.), prepositions and adjectives are characterised by a stable meaning, relatively independent of the context in which they are used. Articles have no specific reference to the context, and tend to covary with the nouns. Pronouns ("we", "it", "your", etc.), on the other hand, derive their meaning directly from the context. Interjections ("Ha!", "Oh!", etc.) and the most often used adverbs ("yes", "no", "still", "then", etc.) are typically used to react to what has happened or has been said before, and do not make much sense without that context. Verbs depend on the context because they refer implicitly to a particular time through their tense (time deixis, cf. Levelt 1989), and to a particular subject through their inflection (person or object deixis).

Thus, we can categorize words depending on whether they are used mostly for context-dependent or context-independent expression. This seems to imply that the formality of a text or linguistic expression could be measured by counting the frequency of the more context-independent words relative to the more context-dependent ones. Therefore, my colleague, the linguist Jean-Marc Dewaele and I have proposed the following formula as a "measure" of formality (Heylighen & Dewaele, 1999):

F = (noun frequency + adjective freq. + preposition freq. + article freq. – pronoun freq. – verb freq. – adverb freq. – interjection freq. + 100)/2

The frequencies are here expressed as percentages of the number of words belonging to a particular category with respect to the total number of words in the excerpt. F will then theoretically vary between 0 and 100% (but obviously never reach these limits). The more formal the language excerpt, the higher the value of F is expected to be.

Applying the formula to data about word frequencies in different languages (Uit den Boogaert 1975; De Jong, 1979 for Dutch; Bortolini et al. (1971) [A], and Juilland & Traversa (1973) [B] for Italian; Hudson, 1994 for English) confirms this hypothesis. Figures 1-3 reflect the ordering according to the formality measure of different genres or sources of language. The order agrees both with intuition and with the present characterization of formality. Note in particular that scientific and technical literature, together with informational writing, get the highest score for formality, while spoken language and in particular conversations score lowest. Novels and short stories get an intermediate score. This confirms our general assumption that communication that is more direct or involved, i.e. where the communicators share the same physical context, will be less formal, while expressions that tries to try to convey universal facts independent of a specific context are more formal.

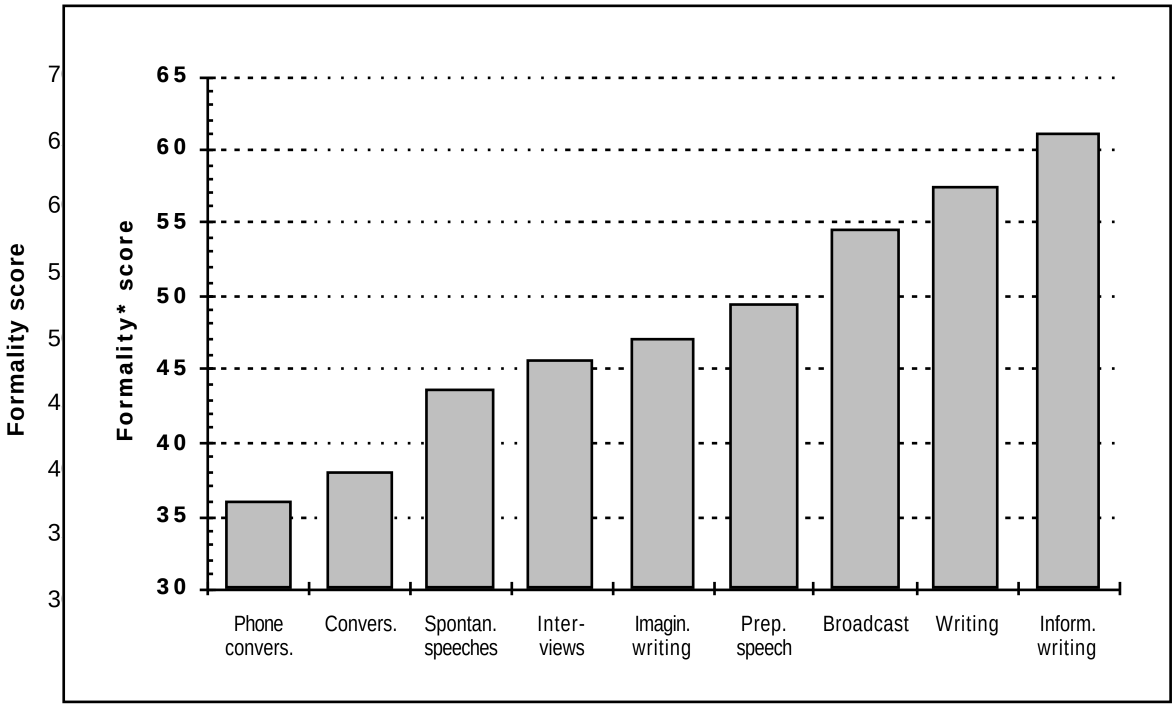
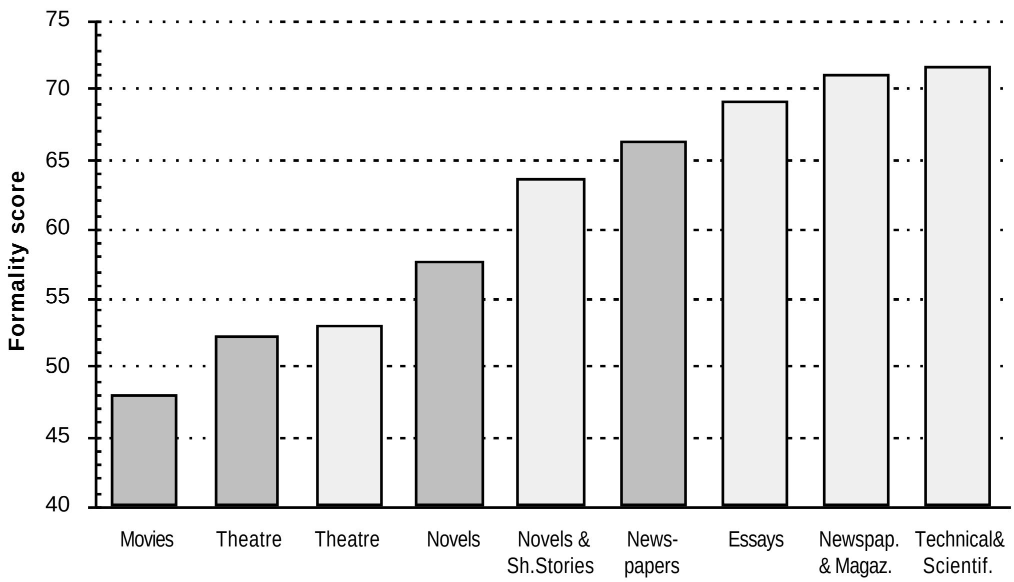


Figure 3: formality scores for English language coming from different fields.
Figure 1: formality scores for Dutch language coming from different fields



Some other findings are more surprising, though. The formality measure not only correlates with the formal requirements of the situation, but also with some intrinsic personality characteristics: gender, introversion and education level. As shown in fig. 1 and confirmed by Dewaele’s (1998) original research on students' French, women’s speech appears markedly less formal, i.e. more context-dependent, than men’s speech. This seems to confirm general sociolinguistic observations (Tannen, 1992), according to which women pay more attention to feelings and to personal relationships, whereas men focus more on external, objective ‘problems’, thus distancing themselves more from their immediate context, a difference in attitude that leads to many difficulties in communication between the sexes.

Formality also seems to be positively correlated with *introversion* (Dewaele, 1994; Furnham, 1990). A possible interpretation is that introverts spend more time reflecting on what they do or say, thus partially detaching themselves from the context, whereas extroverts are quicker to react, paying more attention to external stimuli (context) than to internal trains of thought.

Less surprising is that people with an academic degree tend to be more formal in their speech than people without such a degree (see fig. 1). This can be understood from the general emphasis that academic education puts on unambiguous, accurate expression, and on the fact that formal expression requires a larger vocabulary and more extensive cognitive processing.

The three findings together seem to reinforce the old cliché that mathematicians, computer programmers and scientists, the professionals who pay most attention to formal expression, are typically male, introverted and academically educated. It goes without saying that this does not mean that women cannot be good mathematicians (my own experience would rather point to the opposite), only that given our present cultural (and possibly biological) background formal expression comes more naturally to introverted men.

The results of this empirical study of formality in every-day language are still only sketchy, and need to be confirmed by many further studies, but they open the way to some concrete, and non-trivial applications, e.g. in the tackling of communication problems, or the didactics of formal theories. Together with the formal-computational approaches sketched above, such empirical studies may form the starting point for a general theory of formality and context-dependence, and the different variables to which they are related.

9. Conclusion

One of the fundamental characteristics of scientific modelling is formalization: the expression of ideas in such a way that they are maximally independent of a specific context. This is what allows science to claim universality and objectivity for its results, and makes its theories likely to maintain and spread. Therefore, it might seem that scientists should strive for complete or maximal formalization. This paper has argued that complete formalization is neither possible nor desirable. Formalization will only be possible to the degree that the domain being modelled allows for relatively stable or invariant categories. Even in the most stable domains, such as mathematics and physics, though, the context can never be completely eliminated, as illustrated by the limitation principles formulated by Gödel and Heisenberg. Formality will only be desirable to the degree that it does not impose undue cognitive load on the people who are to understand and apply the models, and does not "close" the model, making it rigid and difficult to extend. This paper has indicated some initial approaches towards determining the optimal degree of formality, either on the basis of theoretical arguments, computer models or empirical measurements. These can be seen as the first steps towards a new, metascientific model, which tries to understand formality and context-dependence in a more formal manner.

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