

Letter to the Editor

Evolution of the International System of Units: considering the challenge of user adoption

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Abstract

This discussion considers the challenge of making amendments to the International System of Units (SI) in terms of the varying levels of adoption of these amendments by users of the SI. It categorises possible amendments along two scales. First, whether these are changes or additions to the SI; and second whether these amendments are optional or compulsory. Where amendments fall on these two scales gives an indication of whether they are low-risk or high-risk actions, in terms of their likely adoption by users of the SI and the confusion that lack of adoption might cause. Proposed amendments to the SI of current interest are considered with respect to this framework.

Keywords: international system of units, metrology, SI prefixes, angle, dimensionless quantities

1. Introduction

The International System of Units (SI) [1] represents the result of many years of scientific progress and consensus. Importantly it also represents the outcome of cultural, political and historical compromises and has become the only globally accepted system of units. It is a practical system designed to be used and to be useful: it has become familiar to a global community who make use of its conventions providing the definitive approach and basic language for science, technology, industry and trade. Indeed the original intention of the metric system was that it should be available to everyone, anywhere, anytime.

It is a necessary property of the SI that it defines the most fundamental and underpinning principles of the globally agreed measurement system—a consistent and coherent system of units. The SI Brochure provides clear guidance not only on the formal constituent parts of the SI: the seven defining constants of the SI, the SI base units, the SI derived units and the SI prefixes; but also on good practices in application of the SI: non-SI units that are acceptable for use with the SI, how to write unit symbols and names, and how to express the values of quantities. The definition of defining constants, base and derived SI units might be summarised as the ‘how to get the right results’ part of the SI—the essential requirements to achieve measurement stability, comparability and coherence. The elaboration of SI prefixes and the guidance on writing unit symbols and expressing measurement results could be described as the ‘how to get the results right’ part of the SI—important guidance on the unambiguous, universally understood communication of measurement results. (Note how the dividing line between these two descriptions of the SI is not the same. SI prefixes are a formal constituent part of the SI but are considered together with good practices in application and

¹ The views presented are those of the author and do not necessarily represent the views of NPL Management Ltd



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communication under the ‘how to get the results right’ part of the SI.)

It is understandable that with such a varied and rapidly evolving science and technology landscape the SI Brochure is not a perfect fit for every scientific endeavour. There exists, to varying extents, local implementation of the SI principles specific for different technical fields. This might include the use of field-specific non-SI measurement units, legislation within sovereign states allowing non-SI units in weights and measures, the invention of new units in emerging metrology areas, or the altering of unit symbols to allow for machine readability. In all cases the SI remains the point of stability, from which local implementation extends away, but with which contact must never be lost.² It is perhaps important to note that local implementation rarely if ever involves changes to the definition or size of SI units themselves,³ most usually it describes the use of non-SI units or non-standard methods of expressing results.

2. Discussion

Since it was given its name officially in 1960 the SI has itself from time to time undergone amendments [2]. These have always reacted to clear opportunities to provide an improved system, often adopting officially what was already common usage and practice elsewhere—for example in the adoption of the mole as a base unit of the SI absorbed much of what was already common practice within the chemistry community. It is clearly important to think very carefully about making amendments to the SI and ensure they always tend towards improvement for users. For instance amendments should provide increased flexibility or reduced uncertainty. Naturally, such amendments would usually represent gradual evolution of the system rather than sudden step change. In considering this there are conceptual differences to be drawn between amendments to the ‘how to get the right results’ part of the SI and the ‘how to get the results right’ part of the SI. As an example the recent revision of the SI [3] (the ‘how to get the right results’ part)—however fundamental for National Metrology Institutes—involved little or no immediate change for users but will provide significant benefits over time without users needing to take action. (Pedagogical or philosophical considerations of the teaching of the revised SI, where there might be considerable change, would be considered a local implementation issue in this context [4]).

Rapidly evolving technology puts pressure on the SI for change, but there is a need to balance stability and utility of the system when considering amendments. More importantly is the challenge of the adoption of any amendment to the SI by users, especially the global scientific community.

For an amendment to be successful it must be acknowledged and understood by all, and appropriately adopted, even if it is subsequently subject to adaption for local implementation. We might consider possible improvements to the SI which, however technically valid, are taken no further since they would never be fully adopted and their lack of adoption would cause confusion. In fact the interplay between the evolution of the SI and adoption by users is subtle and must recognise the range of amendments to the SI that are possible. First, at one end of a possible scale, are changes or replacements to existing components of the SI and at the other end, additions or extensions to the existing SI. Another scale considers at one end, amendments to the SI whose use is optional and at the other end amendments whose use is mandatory. Figure 1 displays these two axes orthogonally and proposes where proposed amendments to the SI of current interest might sit on such a plot. Taking topics discussed at the last Consultative Committee on Units (CCU) [5] and without considering the relative merits of the technical cases for these proposals, only the challenges of their adoption, figure 1 provides a framework for understanding the risk of these and similar proposed amendments to the SI. In broad terms the challenge of user adoption, and therefore the risk of introducing the amendment, increases from bottom left to top right in figure 1, as amendments move from being optional additions to the SI through to being compulsory changes.

Considering first the discussion about whether angle should be a base quantity within the SI, with its own independent dimension [6], it is clear that this would be a change to the SI because currently angle is considered as a dimensionless quantity. It would also be a compulsory change: angle must either exist within the SI having dimension or not having dimension, but the two states cannot coexist. Partial implementation of such a change would cause significant confusion. This is therefore a high-risk amendment to the SI. Second, consider proposals for new SI prefixes [7]. This is an addition to the SI, an extension to the range of SI prefixes not replacing any current prefixes but adding to them. Its usage is also optional. Just as with the existing range of prefixes, measurement results can equally be expressed using scientific notation, the two systems may happily coexist without any confusion, as they do now. As such this can be considered as a low-risk amendment to the SI.

Two other significant topics are currently under discussion by the metrology community: ‘counting units’ to distinguish different items that may be counted [8], and adaption of the SI to the digital world [9]. These topics might be considered to lie at the other corners of figure 1. New ‘counting units’, for example for ‘cycle’, would be an addition to the SI—the unit 1 would continue to exist—but in order to achieve the benefit from this addition it would be necessary to use these ‘units’ in the appropriate context. It therefore might be considered as a medium-risk amendment to the SI: an addition, but one which, if only partially implemented, would not achieve its full benefit and may risk some confusion. However, if not fully implemented the level of confusion caused to the user would be arguably much less than partial implementation of angle as a base quantity. The adaption of the SI to

² An analogy might be that the SI is the drawing pin (thumb tack if you prefer) in the drawing board of metrology, from which the elastic band of local implementation stretches, but never breaks, and to which it must always eventually return.

³ Excluded from this are the use of other unit systems, or consideration of ordinal quantities and nominal properties which, whilst still beneficiaries of good metrology principles, are not part of the SI.

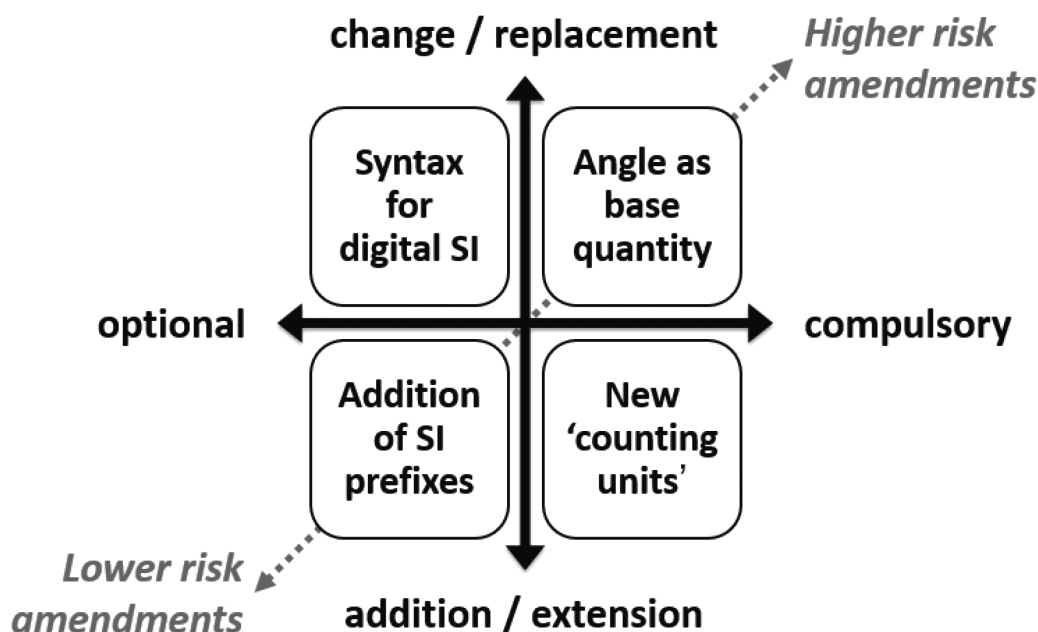


Figure 1. Diagrammatic consideration of current proposals for amendments to the SI, their relative properties and challenge of adoption, expressed as risk, with respect to users of the SI.

the digital world is a very large topic but here only changes to syntax to allow machine readability are considered. This might be thought of as a change to the SI, perhaps involving the introduction of different characters—for example to distinguish milli from metre, or provide ASCII characters for Ω and μ . This is a change that would be optional for users depending on whether their application required machine readability or not. Whilst potentially useful this change could cause confusion if the user did not understand the context of usage. This is therefore another medium-risk amendment to the SI. It is lower risk that the introduction of angle as a base quantity, but arguably higher risk that new ‘counting units’ since the existence of two systems could cause some level of confusion, rather than just a lack of benefit.

Given that the SI must be of benefit for all users, the level of risk of implementation and adoption is a key factor in considering which amendments to take forward. At a first approximation, and given a compelling technical case, one might propose that low-risk proposed amendments are suitable for adoption into the SI. Medium and high-risk proposed amendments would probably not be suitable for inclusion directly into the SI without significant further thought. However, medium-risk proposed amendments might instead be suitable instead for local implementation downstream of the SI in documentary standards or other guidance covering relevant technical areas if they deliver sufficient benefit to counter any risk. High-risk proposed amendments could be suitable as solutions for specific technical problems (for example the use of complete equations in software to solve the ‘angle problem’ [10]) where their high risk would be properly controlled and not affect wider technical areas.

So far this treatment has considered the effect on the end user and has, angle as a base quantity aside, considered

changes to the ‘how to get the results right’ part of the SI. It is notable that the recent revision of the SI, and also the proposed future redefinition of the second, have very little effect on the end user (if the revision has been properly performed and unit sizes have not changed) [3]. Nonetheless, these issues would still be regarded as a high-risk, compulsory changes to the SI. Here this is not because of the challenge of implementation (educational aspects aside) but more because of the requirement to ensure continuity with previous definitions and sufficient ongoing resource at National Metrology Institutes (NMIs) to support the change (for example a minimum number of Kibble balances in operation worldwide). This risk is shouldered by the NMIs, a smaller and more coherent, tractable and collaborative community than the general user base of the SI, and so in this context this amendment to the SI is deemed acceptable despite its high-risk. Furthermore, it is a general observation that amendments to the ‘how to get the right results’ parts of the SI (e.g. changes to unit definitions and quantity dimensions such as for angle) will be necessarily higher risk since they have the qualities of compulsory changes not amenable to local implementation. Conversely amendments to ‘how to get the results right’ parts of the SI (e.g. new SI prefixes, expression of measurement results) will often be much lower risk since they are more likely to have the qualities of optional additions and feature regularly in local implementation downstream of the SI. An example of a lower risk amendment to the SI in relatively recent times was the addition in 1991 of the SI prefixes zetta, zepto, yotta and yocto for 10^{21} , 10^{-21} , 10^{24} and 10^{-24} , respectively. At the time the stated need for new sub-multiple SI prefixes was to express molecular quantities in SI units whose magnitude was more suited to molar quantities, as improvements in

analytical chemistry allowed the measurement of ever smaller amounts of substance. Despite those sound intentions these SI prefixes have not to date found significant use in the literature [7]. Equally, however, there have been no documented cases of their introduction causing any misuse, confusion or mistakes. It was a very low risk amendment to the SI. In 1991 the reason to introduce the multiples zetta and yotta was simply to match the extension in the submultiple range with no clear driver for their future use. Now, of course, these prefixes are extensively used in information technology to describe data storage (e.g. zettabytes) in a way that could not have been envisaged in 1991. This was also a very low risk amendment to the SI but one with unforeseen positive consequences.

3. Conclusions

The SI is a well-known and well-used system but is not immune to the requirement for change because of external pressures. Various amendments to the SI are regularly proposed based on differing technical cases. This discussion has tried to demonstrate that these technical cases alone are necessary but not sufficient to amend the SI. A further, perhaps more important, consideration is the nature of the change and how this might affect its implementation and adoption by users of the SI. Various cases of proposed amendments of current interest have been considered according to this mechanism and this has led to the conclusion that, regardless of technical arguments, these actions can be ranked in terms of risk. It has been proposed that lower risk actions may be suitable for inclusion in there SI, whereas higher risk actions need much more consideration. Some of these higher risk actions may be more amenable to local implementation downstream of the SI, for instance in standardisation. Other higher risk actions, for instance the future redefinition of base units such as the second, require other assurance before implementation, such as ongoing available resource at NMIs to realise new definitions.

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