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Euclidean terms in European languages, 1482–1703

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ABSTRACT

This paper reports on the degree of lexical instability in European translations of the *Elements* published up to the end of the seventeenth century. As well as the intrinsic interest of the formation and stabilization of a Euclidean tradition in these languages, the wide visibility of Euclidean material in the period makes it likely that the terminological choices made by early translators were influential in the wider formation of mathematical vocabularies in the languages concerned. The paper shows that instability was distributed unevenly across languages and semantic areas, and reports where the pockets of higher and lower instability were located.

1. Introduction

Euclid's *Elements of Geometry* was composed or compiled in Greek around 300BCE. By the period of the European invention of printing in the fifteenth century, the text had been translated into a number of other languages, including notably Arabic, Hebrew and Latin (Vitrac, 1990, Rommevaux et al., 2001, Murdoch, 2008). The sixteenth and seventeenth centuries saw translations into at least seven new languages. There has been some discussion of the lexical choices made by translators into Arabic (from the ninth century onwards) (see for instance De Young, 2002/3) and Mandarin (in the early seventeenth) (Engelfriet, 1998), and also of the presence in the medieval Latin tradition of words transliterated from the Arabic version(s) of the text (Busard, 1983, 2005). The choices made by translators into European languages during the sixteenth and seventeenth centuries have received much less comment. Part of the reason for this is likely the sheer number of early modern versions and the complexity of their mutual relationships.

This paper reports on the degree of lexical instability in European translations of the *Elements* published up to the end of the seventeenth century. It uses the recent catalogue by Wardhaugh et al. (2020) to manage the set of textual versions surveyed. Certain terms, including all of those with some currency outside geometry, clearly already possessed uncontroversial vernacular renderings and show no – or minimal – variation from one translation to another in any given language. Other terms, however, lie at the other extreme, with different translators making up to half a dozen different choices within a single language. As well as the intrinsic interest of the formation and stabilization of a Euclidean tradition in these languages, the wide visibility of Euclidean material in the period makes it likely that the terminological choices made by early translators were influential in the wider formation of mathematical vocabularies in the languages concerned.

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2. Method

2.1. Versions of the text

The most recent catalogue of Euclidean editions in this period is (Wardhaugh *et al.* 2020), which has been used as the basis for the selection of early modern printed versions for the present study. It covers the printed versions from the 1482 *princeps* (Erhard Ratdolt's printing of the fourteenth-century Latin version by Campanus of Novara) to the (relatively) scholarly Greek and Latin version by David Gregory (and, largely unacknowledged, Edward Bernard (Beeley, 2020)) that appeared at Oxford in 1703. It lists in total 228 printed versions of the *Elements* from this period. Certain of these are reissues in whole or in part of printed sheets already issued for sale, and many are word-for-word reimpressions of previous versions of the text(s) in question. Even when these cases are omitted, however, something like ninety actually distinct versions of the *Elements* were printed in the period in question.

For the Greek text, this study uses the edition of Heiberg (Heiberg/Stamatēs, 1969–77) as a reference, including for the numbering of definitions and propositions where it is necessary to refer to these. The version printed by Grynaeus in 1533 was also compared. The latter was the only complete Greek printing of the text until 1703, and its terminological choices differ only in accidentals from those appearing in the Heiberg text. As is well known, it was not until the nineteenth century that any Greek manuscript was subjected to text-critical study which contained a text differing substantially from the main set of so-called Theonine manuscripts (Peyrard, 1814). For that reason, the Greek text visible in the sixteenth and seventeenth centuries may be considered stable in respect of the vocabulary choices studied here.

In Latin, Wardhaugh *et al.* list 12 relevant families of versions of the text (their Dou and *ps.*-Tusi types do not exist in Latin; their Maurolicus type contains only books 13–15 of the text and therefore covers none of the definitions of interest here). The sample used in the present study includes the earliest printing of each, namely in their designations the editions Venice 1482, Venice 1505, Paris 1516, Paris 1552, Paris 1557, Paris 1566, Pesaro 1572, Rome 1574, Antwerp 1654, Paris 1634 and Oxford 1703 (complete citations are given in Appendix 1). These certainly do not encompass all of the variation to be found in detail among the approximately fifty distinct Latin versions of the *Elements* from this period, and it is acknowledged that they represent a sample from that population. The well-known 1516 edition by d'Étaples (on which see Oosterhoff, 2018) was compared but is not used in what follows: at the level of vocabulary choices (and probably more generally) it is an accurate transcription of its two sources Venice 1482 and Venice 1505 and should not be considered an independent version of the text.

Six European vernaculars are represented in the catalogue, namely Italian, French, Spanish, German, Dutch and English. (Both 'Dutch' and 'Italian' here include a range of dialects, on which the paratexts in some cases make explicit statements: Cajani for instance states that his 1545 version is 'in Lingua Thoscana'. For the purpose of the present discussion it seems more helpful to lump these cases than to split them; but see the discussion in §3 below.) The present sample includes every printing in one of these languages that is not described by Wardhaugh *et al.* as a reimpression or reissue of an earlier vernacular model. In a few cases this principle is modified in order to allow a reimpression to stand for its less accessible ancestor. We thus include 53 versions of the text, as summarized in Table 1. They are listed in full in Appendix 1.

Something must be said here about the many Euclidean or para-Euclidean volumes from this period which are excluded from this study. First, manuscript versions of the *Elements* continued to circulate during this period, including not only the existing medieval Latin versions of the text but in some cases new translations, for instance into Italian. The study of the Euclidean manuscript tradition in this period is at a very early stage, and it does not yet seem feasible to include these versions in a systematic comparison such as the present one. That said, it should be emphasized that the present study examines the appearances of the *Elements* and its vocabulary specifically in print, which may in some vernacular languages have been preceded in manuscript versions by some decades.

Second, the sixteenth and seventeenth centuries saw the publication of a large number of what might be called para-Euclidean works, which fall short of being editions of the *Elements* on any reasonable definition but which reproduce the mathematical content of substantial portions of that text paraphrased and/or rearranged. A partial list appears as an appendix to Wardhaugh *et al.* 2020; the number of such works is certainly large in comparison to the number of actual editions of the Euclidean text. No comparative study can feasibly include these works without opening up a hopelessly unstable set of terms and contexts, yet there are certainly cases in which such works were crucial for the introduction or development of a Euclidean vocabulary in a given language. One prominent example is the 1551 *Pathway to Knowledg* of Robert Recorde, which includes definitions of a substantial number of Euclidean terms. In Latin, Giorgio Valla's *De expetendis* (Venice, 1501) and Oronce Finé's *Protomathesis* (Paris, 1532) are similarly important; as in both Latin and Italian is Borelli's *Euclides restitutus* (Pisa, 1658). In all of these cases and many more, it would be of real value to examine the dependence of early Euclidean translators on non-Euclidean and para-Euclidean models for their vocabulary. For the purpose of the

Table 1
Texts included in the sample, by language.

Language	Number of texts collated	Dates
Latin	12	1482, 1505, 1552, 1557, 1564, 1566, 1572, 1574, 1634, 1654/1665, 1655, 1703
Italian	5	1543, 1545, 1651, 1671, 1690/1746
German	6	1555, 1562, 1610, 1618, 1694, 1697
French	12	1564–5, 1598/1605, 1610/1613, 1611, 1615, 1622, 1634, 1654, 1672, 1677, 1682, 1693
English	7	1570, 1651, 1660, 1661, 1680–81, 1685, 1685
Spanish	5	1576, 1637, 1665, 1688, 1689
Dutch	6	1606, 1617, c. 1620?, 1633, 1695, 1702.

present study, however, it is hoped that the advantages of a stable, easily comparable corpus and a focus on the specific context of editions and translations of the Euclidean text can outweigh the obvious disadvantages of not surveying the early modern Euclidean tradition in a more comprehensive sense.

2.2. Vocabulary items

Somewhat more than 100 terms are explicitly defined in the Greek text of the *Elements* established by Heiberg. It is not uncommon for a single numbered 'definition' to provide definitions of more than one term; Heiberg's definition 1.22, for instance, introduces all five of the terms *τετράγωνον* [square], *ἑτερομήκης* [oblong], *ῥόμβος* [rhombus], *ῥομβοειδής* [rhomboid] and *τραπέζιον* [trapezium]. Conversely, some 'definitions' paradoxically define no new term but state the relationship between entities already defined (some such cases are arguably axioms (see de Risi, 2016)). Again, certain terms are defined more than once, in different contexts, such as *μέρος* [part] (defs 5.1 and 7.3) or *ὅμοιος* [similar] (defs 3.11, 6.1 and 7.21, 22). Other terms are used in technical senses without definition, including structural or logical markers such as *ὅρος* [definition], *αἴτημα* [postulate] and the closing formula *ὅπερ ἔδει δεῖξαι* [what it was required to prove].

The version of the Greek text printed in 1533 by Grynaeus defines a very few extra terms, although its definitions are not explicitly designated as such nor numbered, and it is therefore not always unambiguous which terms (if any) are intended to be defined. Versions of the text in other languages, on the whole, provide explicit definitions for rather more terms; and it is not unusual for a single Greek term to be presented in a single vernacular text with two or three alternatives: 'figure de quatre côtez; quadrilatere; quadrangle', for example (Paris 1693). Some texts – including of course abridgements – define fewer terms. In all cases, definition numbering, where present, differs widely from one version of the text to another.

For this study, terms defined or introduced within the definitions in Heiberg's text were collated, plus the following terms introduced or defined in postulates or propositions:

- *ἄγω* [draw]: postulate 1
- *ἐκβάλλω* [produce]: postulate 2
- *γράφω* [describe]: postulate 3
- *βάσις* [base]: used from prop. 1.4 onwards but not defined until book 11
- *παραλληλόγραμμον χωρίον* [parallelogrammic area]: prop. 1.34
- *μέση* [medial]: prop. 10.21
- *ἐκ δύο ὀνομάτων* [binomial]: prop. 10.36
- *ἐκ δύο μέσων* [bimedial]: prop. 10.37
- *μείζων* [major]: prop. 10.39
- *ἀποτομή* [apotome]: prop. 10.73
- *ἐλάσσων* [minor]: prop. 10.76
- *στερεός παραλληλεπίπεδος* [parallelepipedal solid]: prop 11.25

Also included were the following extra terms usually defined in the Latin and vernacular versions of the early modern period:

- ***ordinata proportio*** [ordinate proportion], usually preceding def. 5.18, *τεταραγμένη ἀναλογία* [perturbed proportion];
- *ἀντιπεπονθώς* [reciprocally related], usually following def. 6.1, *ὅμοιος* [similar];
- *πηλικότητες* ['size' of a ratio], appearing in the spurious def. 6.4;
- *τετράεδρον* [tetrahedron], usually following def. 11.25, *κύβος* [cube].

Not included, however, were the (long) sequence of Latin ratio terms such as ***superpartiens*** and ***sesquialtera***, inserted into book 5 by some editors; when these terms appear in modern languages it is invariably as obvious borrowings from Latin.

Compounds which introduce no new word, such as *ἀρτιάκις ἄρτιος* [even-times even], were not included. Duplicates were removed except for a few cases where is it clear that a difference of meaning is intended or vernacular renderings normally differ (*πέρατα* is the clearest example, variously meaning ***ends, edges*** or ***faces*** depending on context, although some vernacular translators achieve a single term such as ***extremities*** (Heath)). For the discussion of semantic areas in §4.2, judgement was used in the placement of duplicate terms: *κύβος* [cube] is placed in book 11 rather than 7, for instance; in cases of doubt (such as *ὅμοιος* [similar]) first appearance was the deciding factor.

Also collated were the terms used as structural articulations below the level of 'book', namely *ὅρος* [definition], *αἴτημα* [postulate], *κοινὴ ἔννοια* [common notion], *πόρισμα* [porism, corollary] (*e.g.* in prop. 3.1), *λῆμμα* [lemma] (*e.g.* in prop. 10.13), *ὅπερ ἔδει ποιῆσαι* [what it was required to do] and *ὅπερ ἔδει δεῖξαι* [what it was required to prove]; plus, finally, ***propositio*** [proposition], ***problema*** [problem, construction] and ***theorema*** [theorem], absent from the Greek texts but very common elsewhere.

The complete set of collated terms is listed in Appendix 2; it numbers 124 items.

2.3. Caveat lector

The complete dataset is available as an online supplement to this paper.[1] It will be clear from what has been said that this is a complex and messy set of data, in which a one-to-one correspondence between items of vocabulary in different texts is the exception rather than the rule. This means that attempts to count the occurrences of particular lexical phenomena, undertaken in this and the following sections, must always be taken as approximations. In two particular respects, judgement has been exercised in order to arrive at the counts which follow.

First, for the purpose of deciding whether two texts use the same or different terms for the same concept, differences in spelling have been disregarded: such as between *spera* and *sphaera*, or between *middellinie* and *middel-lijn*. Also disregarded are differences in the grammatical form – such as differences of number or, occasionally, gender or case – in which the word defined appears: *termini vs. terminus*, for instance. Finally, this study also disregards occasional differences as to which part of speech is defined, such as between *prime numbers* (where *prime* is an adjective) and *primes* (where it is a noun). Ambiguous word forms and sentence constructions of this last kind are not uncommon, reflecting a rather general tendency in mathematical writing for properties and operations to become reified, that is for adjectives and verbs to reappear as nouns in later texts.

These principles are easier to state than to apply with absolute consistency in practice. When Zamberti introduced *dimetiens* in place of Campanus' *diameter*, it could be argued that this was merely a verbal participle in place of its cognate noun; but here it is taken as an (unsuccessful) attempt to introduce a new noun. Similarly, Latin editors' vacillation between *binomium* and *ex binis nominibus* (def. 10.5) might or might not be taken as two distinct terms, as might *extremum* and *extremitas* (def. 11.2) or *aequa* and *ex aequalitate* (def. 5.17). In all of these cases, this study errs on the side of counting more rather than fewer distinct terms.

A second source of ambiguity concerns the appearance of Latin or transliterated Greek terms in vernacular texts. Some editors, such as van Schooten, accompanied almost every definition with a Latin equivalent term in parentheses: 'middelpunt (centrum)', for instance. Others used marginal notes or a different fount of type for the same purpose, sometimes inconsistently or sporadically. Such cases are naturally omitted from the data given here. But it is sometimes unclear whether such an equivalent – sometimes more or less completely vernacularised in spelling – in fact represents a suggestion that the Latin term be adopted in the language in question. For example, 'der Umbkreiss, Circumferenz, oder Peripheria' (Vienna 1694), 'gnomo, das is, ain winckelhack' (Basel 1562) or 'ghelijcsijdigen-triangel, ofte triangel equilateral' (Leiden 1606). Similarly, a high proportion of editors used the Latin terms *propositio, problema* and *theorema* unmodified, or inconsistently modified, as structural headings within a vernacular text: this too can be read quite naturally as an attempt to naturalise those terms for vernacular use. Included in the present data are Latin and Greek terms which are not visually distinguished from their vernacular surroundings by a change of type, size, italicization, parentheses or placement in the margin. This, again, represents a decision to err on the size of inclusion rather than exclusion.

With these explanations and warnings in mind, the following section presents the results of this investigation, first considering the different pictures presented by the seven languages in which the *Elements* appeared in multiple printed versions in this period.

3. Results

3.1. Latin (1482–1703)

As mentioned above, the Greek texts of the *Elements* visible in the sixteenth and seventeenth centuries do not seem to contain lexical variation of the kind under study here. The Latin versions, however, certainly do; among the 124 vocabulary items surveyed here, the 12 Latin texts collated from 1482 to 1703 show lexical variation in 67 items (54 %).

Before probing the details of this phenomenon, it is of interest to know whether this degree of lexical instability was new in the period of print, or whether it already existed in the Latin geometrical writing of the middle ages. As a comparison, vocabulary terms were collected from the Boethian *Musica* and *Arithmetica* (Friedlin, 1867), the pseudo-Boethian *Geometria* (Folkerts, 1970), Adelard's (first) version of the *Elements* (Busard, 1983) and Campanus' *Elements* as printed in 1482. Of the 109 terms appearing in more than one of these sources, 55 show variation (50 %). Campanus differs from Adelard in 31 of the 101 items they share. These results show that lexical variation was already a feature of Euclidean vocabulary in Latin before the period of print, and on very much the same scale as can be seen in the printed texts. A fuller investigation of the medieval Euclidean texts – which raises complex issues to do with their independence and mutual visibility – would be necessary in order to confirm this, and this would lie beyond the scope of the present study (see further in §5 below).

To return to the printed tradition: much of the variation in that tradition can be traced specifically to the differences between the versions of Campanus and that of Zamberti, printed in 1505. Taking into account the fact that certain terms did not appear in one or other of the texts, Zamberti had 111 opportunities to adopt Campanus' term or to introduce a new one (or both). In 45 cases (41 %), he introduced a new term. These cases included the replacement of Arabic transliterations such as *helmuaym* (in this case by the Greek transliteration *rhombus*). They also included quite a number of ostensibly more indifferent or merely stylistic choices: *postulata* for *petitiones, signum* for *punctus, rectangulum* for *orthogonium*. Certain of the semantic areas most affected by such changes are discussed in §4 below.

To put it another way, 57 of Zamberti's 123 Euclidean terms (46 %) had no precedent in the one printed version of the *Elements* that

[1] See doi:10.1016/j.hm.2024.07.002.

preceded his (45 disagreements with Campanus; 12 terms which Campanus did not define). The role of Zamberti as originator of a large part of the modern Euclidean vocabulary is therefore an important finding of this study, and something that has not been highlighted before (there is a brief discussion of his edition in (Heath, 1926, 1.98); see also (Thomas-Stanford, 1926, 3)). On the other hand, this is a case in which a specific para-Euclidean work was certainly of major importance: Valla's *De expetendis* was a major source for Zamberti's Euclid, an observation which certainly extends to its vocabulary choices and innovations. A full direct comparison between the two works remains to be done, but it is important to acknowledge that while Zamberti introduced these new terms to the context of Euclidean translation – and his version of the *Elements* did a very great deal to disseminate them – it was Valla who originated many of them within the wider context of early modern Euclideanism.

It is natural to ask what the earlier sources were for these new terms. A proportion of them may have existed in earlier mathematical Latin. Specifically in the Boethian and pseudo-Boethian texts, a total of 21 of Zamberti's 57 non-Campanine terms may be found (37 %), and this may give an indication of the degree to which Zamberti/Valla relied on predecessors for their new Euclidean vocabulary.

Another possible source is new transliterations from Greek. Nine of Zamberti's 21 Boethian words are in fact also explicable as Greek loans, together with a further five not used by Boethius (*lemma, apotome, prisma, cylindrus, parallelepipedum*). These numbers are too small for statistical significance, but they suggest reasonably strongly that Zamberti did not turn frequently to Greek transliteration for his new terms. Instead he usually adopted existing Latin words, which were not used in their geometrical sense by Campanus. Examples include *communes sententiae, altera parte longius, tangere, sectio circuli, correlarium*, and, importantly, *ratio* (on which see §4 below).

Few Euclidean editors and translators in the early modern period were at all explicit or specific about the sources to which they had access, but the disagreements between Campanus and Zamberti were fairly highly visible in print: not only in the printed editions of respectively 1482 and 1505, but also in d'Étaples' edition of 1516, where both texts were printed. The text of 1482 was also reprinted by Achates in 1491 and in part by Lacher in 1506 and Scipio Vegio in 1509, while that of 1505 was reissued (a partial reimpression) in 1510.

On the whole, Zamberti's edition was successful in replacing or initiating replacement of Campanus' terms. Subsequent Latin editors followed it much more frequently in the disputed cases than they followed Campanus. For each of the 42 terms on which Campanus and Zamberti disagree, Zamberti's term reappears in an average of more than 6 of the later editions collated here, whereas Campanus' appears in fewer than 2 of them. On average, each later edition contains 22 of Zamberti's preferred terms but only 7 of Campanus' in these disputed cases (and, on average, a further three terms originating with neither Zamberti nor Campanus).

For certain terms, indeed, Zamberti's choice was the only one made by subsequent editors. These include those for which Campanus had an Arabism, which were all replaced by Greekisms: *helmuaym* > *rhombus; similis helmuaym* > *rhomboides; helmuariphe* > *trapezia*. They include several of the names of solid forms: *pyramis, prisma, conus, cylindrus*, for which Campanus had respecively *piramis laterata, corpus seratile, conus piramidis, columne rotunde*. Outside these categories, Zamberti's wholly successful innovations were the classes of triangle *scalenum* and *rectangulum, parallelae* (for *equidistantes*), *magnitudo* (for *quantitas*), *reciprocae figurae* (for *mutuorum laterum*), *commensurabiles* (for *communicantes*) and *inclinationum anguli* (for *site*).

Of the Campanine terms Zamberti replaced, only a handful appeared more than once or twice among later editors: namely *punctum*, which remained the usual term against Zamberti's *signum* (see (Barany, 2014) on the conceptual issues here); *diameter* where likewise Zamberti's alternative *dimetiens* was not widely adopted; and *duplicem* and *triplicem* (of ratios), where the Campanine *duplicata* and *triplicata* remained common (Sylla, 1984).

No later editor in Latin was anything like as active as Zamberti in introducing new terms to the *Elements*, nor as successful. Table 2 shows the number of new terms introduced by each editor. It is notable on the one hand that Zamberti's novel terms nearly equal those of all other editors together; on the other that certain editors – Hérigone, Barrow and Gregory – introduced no new terms at all.

As with Zamberti himself, the preferred source seems to have been existing Latin words from outside the Euclidean tradition; only two of these later innovations are words to be found in the Boethian corpus, and only six are explicable as Greek transliterations. Many of these later innovations received little or no uptake by subsequent editors; those adopted in a majority of the later editions where they could possibly appear all originated with Magnienus in 1557: *communes notiones* (for *communes sententiae*), *segmentum* (for *sectio circuli*), *insistere* (for *comprehendit*), *accomodari* or (*co*)*aptari* (for *congruerum*), *describi circum* (for *circumscribi*), *ex aequalitate* (*ratio*) (for

Table 2
Innovation in Latin editions.

Text	Novel terms
Campanus (Venice 1482)	–
Zamberti (Venice 1505)	45
De Mondoré (Paris 1552)	2
Magnienus/Gracilis (Paris 1557)	15
Dasypodius (Paris 1564)	11
de Foix de Candalle (Paris 1566)	6
Commandino (Pesaro 1572)	7
Clavius (Rome 1574)	1
Hérigone (Paris 1634)	0
Tacquet (Antwerp 1654/1665)	8
Barrow (Cambridge 1655)	0
Gregory (Oxford 1703)	0

equa proportionalitas/ratio), and *extremum* (for *terminus*), as well as the more purely stylistic choice *primi/compositi inter se* (for *adinvicem*).

A different – and, used with some caution, a useful – measure of the different Latin translators' introduction of novel vocabulary items can be arrived at by asking how many of the opportunities to introduce a new term each editor took. Thus, for instance, Dasypodius in 1564 defined or used 122 terms that had been defined or used by one or more of his three predecessors in Latin. In 11 cases (9 %) he introduced a new term. The use of this measure, however, is complicated by the fact that not all editors included the same portions of the Euclidean text in their editions. Among the predecessors of Dasypodius, in fact, the 1552 edition of de Mondoré included only book 10, with the consequence that for nearly all vocabulary items, Dasypodius had in fact two predecessors, not three (and, conversely, de Mondoré himself had only a tiny fraction of the opportunities to introduce new vocabulary compared with most Euclidean editors). This problem becomes much more acute when dealing with the vernacular translations, which frequently include only selected books: and there is a risk of presenting statistics about vocabulary innovation that do not have much meaning. For the purpose of comparison, it is desirable to work with a stable uniform corpus of terms. This can be achieved by limiting comparisons to Books 1–6 of the *Elements*, and excluding the small number of editions (like Mondoré's) which do not include those books. With this restriction in place, the term **rate of innovation** will be used to denote the proportion of occasions on which an editor, instead of adopting a term used by a previous editor in the same language, introduced a new term. That is, of the 88 terms surveyed within books 1–6, what proportion did that editor render using a word that was – in that context – new? Table 3 shows these rates of innovation for the Latin editions after Campanus, and the numbers of new terms introduced specifically in books 1–6.

These remarks and tables give a sense of the stabilization of the Latin Euclidean vocabulary over this period. A diminishing trend over time is clear in both numbers of new terms and rates of innovation, and the latter in fact show a high negative correlation with the order of publication of the edition ($\rho_s = -0.78$). But care is again needed in establishing what these data do and do not mean. The trend in Table 3 might well reflect the fact that later translators, with more vocabulary choices already visible in print, found it less necessary (or less feasible) to introduce new terms. Particularly for choices involving non-technical vocabulary – such as which preposition to use with *primi* and *compositi* or which verb denotes 'possession' of a ratio – one might go further and say that the set of possible terms already existed at the start of the period, editors chose from it more or less arbitrarily, and the natural result was a slowing rate of novel choices.

Another way to interrogate the data is shown in Table 4. Here, the eleven Latin texts (excluding de Mondoré) are grouped by date into three sets of four (overlapping at 1564), and the average number of Latin alternatives representing a single Greek term within that set of texts is tabulated, as well as the total number of Greek terms about whose Latin rendering there was any disagreement.

This shows more clearly that what occurred was indeed a stabilization of the Latin Euclidean vocabulary, with both the average number of Latin terms and the number of disputed terms falling over time. It must be emphasised, however, that a larger sample of Latin texts would be needed for a grouping of this granularity to have statistical validity (see §5).

3.2. Italian (1543–1690)

Five distinct Italian texts of the *Elements* were published in the period; all included books 1–6, but only the translations of Tartaglia (1543) and Cajani (1545) included the later books. Table 5 shows their rates of innovation in books 1–6. All of the innovation in fact occurred in just three texts; Viviani's 1690 text introduced absolutely no terms not found in its predecessors, agreeing with Caravaggi (1671) on nearly every choice (though not every detail of spelling or phrasing).

In fact, the introduction of novelties was overwhelmingly by Cajani in 1545, who replaced more than half of the terms he found in

Table 3
Innovation in Latin editions: books 1–6.

Text	Novel terms	Rate of innovation (%)
Campanus (Venice 1482)	–	–
Zamberti (Venice 1505)	34	44
Magnienus/Gracilis (Paris 1557)	11	13
Dasypodius (Paris 1564)	9	10
de Foix de Candalle (Paris 1566)	4	5
Commandino (Pesaro 1572)	7	8
Clavius (Rome 1574)	1	1
Hérigone (Paris 1634)	0	0
Tacquet (Antwerp 1654/1665)	8	11
Barrow (Cambridge 1655)	0	0
Gregory (Oxford 1703)	0	0

Table 4
Stabilization of Latin vocabulary (books 1–6).

Text group	Average Latin alternatives per Greek term	Number of disputed terms
1482–1564	1.7	41
1564–1574	1.5	31
1634–1703	1.3	21

Table 5
Innovation in Italian translations (books 1–6).

Edition	Novel terms	Rate of innovation (%)
Tartaglia (Venice 1543)	–	–
Cajani (Rome 1545)	42	51
Ricci (Bologna 1651)	23	28
Caravaggi (Milan 1671)	11	13
Viviani (Florence 1690/1746)	0	0

Tartaglia's version. This clearly speaks of a deliberate effort by Cajani to overturn Tartaglia's choices. With only two later texts in this sample, it is difficult to speak meaningfully of his success in doing so; and in fact 22 of the 42 new terms he introduced into books 1–6 were themselves subsequently replaced by either Ricci or Caravaggi (or both). Notable successes among Cajani's innovations are *domande* for *petitione, rettangolo* for *orthogonio, grandezza* for *quantita*, and *divisione di ragione* for *disgionta*, each of which was taken up in all subsequent versions. Conversely, innovations by Cajani with no subsequent uptake were *proposte* for *propositione, spuntato* for *otuso, apuntato* for *acuto, simile al rombo* for *rhomboide, tauolette* for *trapezzie, pari* for *eguali, zeppa del circulo* for *sector/settore*, and *turbata* for *perturbata*. In each of these cases, Tartaglia's term was used in all of the subsequent versions.

As to the absolute degree of variability within this set of texts: 53 of the 88 Greek terms surveyed in books 1–6 were rendered in more than one way by these five Italian translators (57 %). The average number of Italian translations for a given Greek term is 1.8.

3.3. French (1564–1693)

In French, there are twelve complete or partial versions of the *Elements* from the period, beginning with that of Forcadel de Beziés in 1564–5. (Dechales' version of 1677 is included in addition to that of 1672; the later text is described by Wardhaugh *et al.* as 'substantially revised … with new wording in many places', and the present study tends to confirm that it deserves to be treated as a distinct version of the text.) As in Italian, certain versions (1611, 1654, 1682) exclude books after the sixth, while both the 1564–5 and 1598/1605 versions end after book 9, and the 1672, 1677 and 1693 versions include only books 1–6 plus 11 and 12. Numbers of new terms and rates of innovation, both restricted to books 1–6, are given in Table 6.

Innovation was distributed across the work of several translators: Peletier and de Tournes (1611), the two versions of Dechales (1672 and 1677) and Errard (1598/1605). (Ironically, Henrion claimed unusual novelty for his translation of 1615; this was disputed by contemporaries including le Mardelé (1622), and it is not borne out here.) With eleven texts, it is meaningful to compute a rank correlation coefficient between the rate of innovation and order of publication; this proves to show a correlation in the same direction as in Latin, but of smaller size ($\rho_s = -0.43$) evidently because of the trend-defying innovators in 1611 and 1672/1677. Grouping the texts into three sets of four (see Table 7) shows similarly that, by contrast with Latin, the number of disputed terms and the average number of distinct translations per term were not steadily falling during the period. But, once again, it must be emphasised that the sample size is too small for these results to be more than impressionistic.

In French, 52 terms out of 88 show some disagreement (59 %), and across those 88 there are an average of just over 2 French terms for a given Greek word. Nevertheless, the terminology of the first translator (Forcadel) was strikingly successful, and the second or subsequent versions of terms seldom received uptake by a majority of subsequent translators (the average number of subsequent appearances for a non-Forcadel term is around 2). Among the few notably successful later innovations are *faire* (for *demonstrer*; introduced 1611), *demicercle* (for *moitié de cercle*; 1611), *trapeses/trapeze* (for *tablettes*; 1598/1605), *inscripte* (for *descrite*; 1598/1605), *multiplice* (for *plusieurs-fois*; 1598/1605), *raison egale* (for *raison de l'equalité*; 1598/1605) and *diuisee par la moyenne & extreme raison* or similar (for *selon le milieu & les deux extremes*; 1598/1605). All of these were introduced by Errard (1598/1605) or Peletier/de Tournes (1611); the novelties of Dechales (1672/1677) have only two successors within this text and cannot be meaningfully assessed for their success in terms of uptake. It is noticeable that several of these are words or phrases more closely or more obviously related to a Latin equivalent (*faire/facere, demicercle/demicirculus, trapeses/trapezium* (a Greek transliteration), *inscripte/inscriptum, multiplice/multiplex*);

Table 6
Innovation in French translations, books 1–6.

Text	Novel terms	Rate of innovation (%)
Forcadel (Paris 1564–5)	–	–
Errard (Paris 1598/1605)	13	16
Dounot (Paris 1610/1613)	10	12
Peletier/de Tournes (Geneva 1611)	22	27
Henrion (Paris 1615)	2	2
le Mardelé (Paris 1622)	6	7
Hérigone (Paris 1634)	2	2
Fournier (Paris 1654)	6	7
Dechales (Lyon 1672)	10	11
Dechales (Paris 1677)	10	12
Rohault/Clerselier (Paris 1682)	5	6
Ozanam (Paris 1693)	3	4

Table 7
No stabilization in the French vocabulary (books 1–6).

Text group	Terms per Greek term	Number of disputed terms
1564–1611	1.6	36
1615–1654	1.3	24
1672–1693	1.4	31

all but *trapeses* (where a translation is replaced by a transliteration) are arguably more literal renderings of the main equivalent Latin term, though at least one (*raison egale*) is actually poorer as a rendering of the Greek.

3.4. Spanish (1576–1689)

In Spanish, the data are somewhat more sparse. Four versions of the *Elements* appeared containing books 1–6 (1576, 1637, 1688, 1689); the last two of these also contained books 11 and 12. A version of 1665 contained books 5 and 7 only. No Spanish version of book 10 appeared in this period.

Table 8 gives the numbers of new terms and rate of innovation in books 1–6 for the three relevant texts after the first.

There is once again a tendency for earlier translators to innovate more, and Carduchi in 1637 has both the highest number of novelties and the highest rate of innovation, by some margin. Across the 88 Greek terms surveyed in these books, there is an average of just 1.6 Spanish equivalents per term. Of these, 48 exist in just one Spanish version. This confirms the impression of lexical stability in this set of texts.

With so few versions, it is difficult to quantify the success of individual innovations; the tendency was certainly for de Medrano and Kresa to return to Zamorano's terms in preference to Carduchi's innovations. Notable exceptions are *proporcionalidad* (for *proporcion*), *proporcion duplicada/triplicada* (for [*tres*] *dobla da proporcion*) and *contraria proporcionalidad* (for *conuersa razon*).

3.5. English (1570–1685)

In English, Billingsley's version of 1570 included the whole of the Euclidean text, as did those of 1660 and 1661. A version of 1651 contained just books 1–6, and those of 1680–81 and 1685 (two translations) added to this books 11 and 12. Table 9 shows numbers of innovations and rates of innovation for books 1–6.

Like French, English thus shows strikingly little progress from more innovation to less. The version of Rudd (1651) is to some degree a special case, closely modelled on Billingsley's version, whose preface it included: although much of the phrasing was modified in detail, only one actual terminological change within the scope of this study was made (*inordinate* for *perturbate proportionality*). Moore in 1680–81, meanwhile, followed Barrow (1660) closely in his choice of terms. But even if these two are removed from consideration, Hallifax (1685) remains an outlier, with a striking tendency to introduce terms with no precedent in English: *demands, or suppositions, maximes* (= *axioms*); *surface* (for *superficies*); *rectilineal; equicrural* (= *isosceles*); *losange* (=*rhombus*); *aliquot part; similar* (for *like*). Since this version was translated not from Latin but from the French of Dechales (1682), this phenomenon deserves a closer look. All of Hallifax's 19 innovations are explicable as translations or transliterations from Dechales' French, with the exceptions of *equicrural*, for which the Latin of Tacquet (1654) seems the most likely source, and *denominators* as an alternative to *quantities* for *πηλικότητες* (the 'sizes' of ratios), for which a Latin source seems likely (*denomination* was a medieval Latin term for the size of a ratio). In 12 cases, Dechales' word was itself an innovation compared with earlier French versions. Williams' tendency to innovate terminology, however,

Table 8
Innovation in Spanish translations.

Text	Innovations	Rate of innovation (%)
Zamorano (Seville 1576)	–	–
Carduchi (Alcala 1637)	20	25
de Medrano (Brussels 1688)	12	14
Kresa (Brussels 1689)	5	6

Table 9
Innovation in English translations.

Text	Innovations	Rate of innovation (%)
Billingsley (London 1570)	–	–
Rudd (London 1651)	1	1
Barrow (London 1660)	16	18
Leeke (London 1661)	12	14
Moore (London 1680–81)	0	0
Hallifax? (Oxford 1685)	19	23
Williams (London 1685)	8	10

whose 1685 English text was also translated from Dechales, is less marked.

The 88 Greek terms in books 1–6 are represented by an average of 1.9 English terms each; there are 52 disputed terms overall (58 %); both figures are slightly inflated by the tendency of the first translator, Billingsley, to give two (or more) terms for certain concepts: 19 in total. This may be in part because Billingsley consulted multiple Latin sources (see Simkins, 1966). Post-Billingsley innovations were not, on the whole, successful. Of 41 terms for which a non-Billingsley term was later introduced, most in fact show one or more of Billingsley's terms retained by half or more of subsequent translators. Conversely, the post-Billingsley terms taken up by a majority of editors are *axiom* (for *common sentence*), *furthest/farther distant* (for *more distant*), *described about* (for *circumscribed*), (*self-*)*same reason/ratio/proportion* (for *proportionalitie*), *duplicate/triplicate* (for double, triple), *inverse* (for converse), *minor* (for *lesse*), *in/after the same manner* (for *in like sort*). All originated with Barrow in 1660, except *self-same proportion*, which was Rudd's (1651) term.

3.6. German (1555–1697)

The remaining two Germanic languages in this set, German and Dutch, show a strikingly different pattern. In German, only books 1–6 were translated more than once (in fact, five times) in the period: in 1562, 1610, 1618, 1694 and 1697. The earliest partial German version of the text, that of Scheybl (Augsburg 1555), contains only books 7–9; while the first – and in this period, only – version of book 11 appeared in 1694. Table 10 shows the numbers of new terms and rates of innovation in each of the versions of books 1–6, from 1610 to 1697.

These rates of innovation are clearly higher than most of those for translations into Romance languages, English or indeed Latin. Furthermore, this set of texts shows no tendency towards less innovation at later dates. Again, one of these four texts – Curtius' of 1618 – was translated not from Latin but from a Dutch original, namely that of Dou ('Auss H. Ioann Petersz Dou. Niderlandischen andern Edition verteutscht' according to the title page). It might therefore be expected to show a relatively high rate of deviation from its two Latin-derived predecessors; but in fact it has the lowest rate of innovation of the four. Of its 17 innovations, eight appear to derive from Dou's Dutch, though two of these are themselves Greek loans, as are two of Curtius' other innovations.

The 88 Greek terms of books 1–6 are represented by an average of 2.8 German terms each. Fully 79 terms show some variation; exceptions include *gleiche, gleichseittig, die höhe, ain tail/Theil, haben (ain Proportz), ordenlich (proportion)*.

3.7. Dutch (1606–1702)

In Dutch, the picture is similar to that in German. Translations of 1606, 1633 and 1702 included just books 1–6; those of 1617 and 1695 and Nienrode's undated translation (perhaps c. 1620) included the whole text. Table 11 shows rates of innovation for books 1–6.

As in German, rates of innovation are high. There is a moderately significant downward trend in the rate of innovation ($\rho_s = -0.7$). For books 7–11, it may be remarked, the pattern is the reverse, with Voogt in 1695 remarkably willing to disagree with his predecessors Schooten and Nienrode: he was evidently mainly concerned to find Germanic terms to replace Greek and Latin loans: *reedelijke* for *rationael, kleynder* for *minor, een naalde* for *piramis, een bol* for *sphaera, een twaalfgrond* for *dodecaedrum*, and so on across more than three-quarters of the vocabulary of these books.

Across books 1–6, 88 Greek terms are represented by an average of 2.8 Dutch terms each. For 80 terms (90 %) there is disagreement. Often this involves a Latinate term against a Germanic one, but frequently there is also a choice of Germanic words. An example from book 1 is *ἀμβλύς* [obtuse], which is variously rendered as *obtus, botten-houck, wijden, plompen*, or *stompen*. The eleven of Dou's original terms in books 1–6 that escape later replacement are *rechte* (of both lines and angles), *scharpen, sijden*, (*figueren*) *van vier zijden, veelsijdighe figueren, ghelijcsijdigen, rechthouckich, staet* (of an angle in a segment), *grootheyt, de hoochte* and *te hebben* (a ratio). In this situation it is impossible to speak of successful replacements.

Table 10
Innovation in German translations (books 1–6).

Text	Innovations	Rate of innovation (%)
Holtzman (Basel 1562)	–	–
Marius (Ansbach 1610)	34	40
Curtius (Amsterdam 1618)	17	22
von Pirckenstein (Vienna 1694)	30	35
Reyher (Kiel, Hamburg and Leipzig 1697)	47	53

Table 11
Innovation in Dutch translations (books 1–6).

Text	Innovations	Rate of innovation (%)
Dou (Leiden 1606)	–	–
Schooten (Leiden 1617)	33	42
Nienrode (Utrecht n.d.)	30	36
Willemsz (Hamburg 1633)	41	49
Voogt (Amsterdam 1695)	25	29
Coets (Amsterdam 1702)	19	21

4. Discussion

4.1. Comparisons between languages

Table 12 repeats the information given above about the proportion of terms which show variation in each language, and the average number of distinct translations for each term in each language (both limited to books 1–6 and therefore to translations which include those books). But these statistics may risk unfairness towards those languages which received fewer translations during the period, and therefore had fewer opportunities to display differences in the rendering of vocabulary. For the purpose of comparison, the rate of innovation as defined above seems a more useful measure of lexical (in)stability. Table 12 therefore also gives the average of the rates of innovation of the translators after the first in each language: that is in effect, the frequency with which editor/translators who could have adopted a term from a previous printed text in fact introduced one that was novel to the Euclidean tradition in that language. (Slight variations in the number of terms included in different versions of the text do not, we believe, invalidate this exercise at the level of precision attempted here.)

These figures make it clear that in certain languages the Euclidean vocabulary was markedly less stable than in others. In particular, in both German and Dutch, translators introduced new terms on more than a third of the occasions when they had the opportunity to do so; whereas in Latin and French they did so on fewer than one occasion in seven.

The causes of these inter-language differences are not obvious. It might have been expected that languages for which more texts were collated would show a greater degree of variation, on the hypothesis that a significant part of the lexical variation from text to text is mere random 'noise'. But in fact there is a moderate *negative* correlation ($\rho_p = -0.6$) between the number of texts collated for a given language in this study and the frequency of term replacement they display. This is hard to account for, although it does provide some reassurance that the 'noise' hypothesis is not a main explanation of the differences between languages seen here.

The differences may result in part from the relative lexical stability of these languages more generally; it is noticeable that the two languages identified in §2.1 as involving differences of dialect – Italian and Dutch – show high levels of variation compared with, respectively, the other Romance and Germanic languages in this set. Conversely, the stability of the Euclidean vocabulary in Latin may be plausibly connected with the more general stability of the Latin language in this period, which was of course not a first language and for which the high-Renaissance period of linguistic purification was largely over by the time most of these Euclidean versions were printed. It is surely also relevant that Latin had a long pre-existing geometrical tradition, and that its Euclidean vocabulary in particular had had several hundred years in which to stabilise before this corpus of texts began to be printed.

It is noticeable that the Romance languages all have average rates of innovation substantially lower than those of German and Dutch. English, however, has one of the lowest rates of all. A possible explanation for this feature is that in Romance languages, Latinisms were relatively acceptable as geometrical technical terms and no strong effort was made to replace them with words that looked and sounded more obviously native. In English, which had by the sixteenth century a five-hundred year tradition of absorbing vocabulary from French, the same may have been the case. But in German and Dutch this was on the whole less so, and more translators attempted to replace obviously Latin or Greek terms with Germanic alternatives. It is infeasible to test this directly because of the difficulty of identifying Latin loanwords (as opposed to cognates) in Romance languages, that is of establishing when in the history of the language a particular Latin word entered its vocabulary. In support of the claim, though, it may be noted that even the Greek and Arabic transliterations to be found in the Latin versions of the text – *trapezium, helmuayn* – seem to be more common in Romance languages and English than in German and Dutch. *Helmuayn*, for instance, is found in neither German nor Dutch, but in both Italian and Spanish.

A final factor, which is also hard to investigate precisely, concerns change in translators' behaviour over the two centuries represented by this study. The results presented in Section 3.1 suggest that the Latin vocabulary was stabilising over the period, with the rate at which new terms were introduced, the average number of Latin alternatives for each Greek term, and the number of terms subject to disagreement, all falling over time. The overwhelming majority of vernacular versions of the *Elements* collated here derived from Latin models either directly or indirectly. (Curtius translated into German from Dou's Dutch, which was in turn translated from the Latin of Holzmann and Errard. Similarly, Williams and Hallifax both translated into English from the French of Dechales (Paris 1677a), which was based in turn on Dechales' own Latin, itself derived apparently from that of Clavius (Rome 1574), not necessarily directly.) The only vernacular editions of the period whose paratext states that they were translated directly from Greek are the German version of Holtzman (Basel 1562) (the first German version of books 1–6) and the French of Le Mardelé (Paris 1622) (a text which introduced just 7 terminological novelties compared with its predecessors, which does not argue strongly for its independence from the pre-existing French Euclidean tradition).

Table 12
Variation and innovation across languages (books 1–6).

Language	Terms showing variation (%)	Translations per term	Average of rates of innovation (%)
Latin	53	1.9	13
Italian	60	1.9	23
French	58	2.1	10
Spanish	45	1.6	17
English	58	1.9	11
German	89	2.8	38
Dutch	90	2.8	36

It might therefore be expected that vernacular translators working at later dates would follow their Latin models in displaying less variable terminology (even if each individual translator did not necessarily consult more than one Latin version). As we have seen, in each Romance language there is indeed a reasonably clear trend from more innovation by early translators to less by later translators; there is also a fairly marked tendency for the second version in each language to undertake more vocabulary replacement than any subsequent version. But in the Germanic languages there is no such trend. As a result, a complete tabulation of translators' rates of innovation against the order in which their versions were published shows negligible correlation ($\rho_s = -0.19$). The correlation rises if only Romance languages are included, but it is still low ($\rho_s = -0.49$). Evidently the greater stability of the Latin vocabulary was not decisive for vernacular translators' practices.

4.2. Comparisons between semantic areas

It is also possible to break down these results not by language but according to the different sections of the Euclidean text. Debate continues as to how the *Elements* should be considered to be structured, or indeed whether its structure is the result of planning by a single author/editor or of accumulation under several hands. In Appendix 2 the terms collated are grouped under the following headings: logical/structural, plane geometry (books 1–4, 6), ratio and proportion (book 5), number theory (book 7), irrational lines (book 10) and solid geometry (book 11). The same set of headings was used in the following analysis. For each term, it is possible to establish the number of languages in which variation is found. The term *ὅρος* (definition), for instance, is represented by a single translation in each of Latin, Italian, French, Spanish and English. In German it is represented by three different terms, and in Dutch by three. Thus of the seven languages in which it appears, it shows variation in two (29 %). This exercise quickly reveals groups of terms which show higher levels of variation. Its average for each of the six groups of terms is shown in Table 13, as well as the proportion of terms in the group which vary in more than half of the languages in which they appear.

On each measure, the number theory terms are the most stable. No term in this section of the text shows much variation; *ἀριθμός* [number] shows no variation in any language, and *μονάς* [unity] and *ἄρτιος* [even] vary only in Dutch. Conversely, the only term in this group showing variation in a majority of the languages in which it appears is *πρὸς ἀλλήλους* [towards one another], not a specifically mathematical phrase.

The next higher rate of variation – on both measures – is shown by solid geometry. All sixteen of its terms show variation in Dutch, and most also in Latin and Italian (book 11 was translated into German only once in the period). The key terms *στερεός* [solid] and *πέρας* [extremity, bound] vary in all languages except German; *στερεός παραλληλεπίπεδος* [parallelepiped] in a majority of languages.

Plane geometry, irrational lines, and the logical terminology of the *Elements* show intermediate levels of variation, with most terms varying in most languages. Within the plane geometry books, terms showing variation in all languages are *πέρας* [edge, bound] with two distinct occurrences (bounds of a line, bounds of a plane) which themselves tend to be translated differently (ends, edges), *τρίπλευρος* [triangle], *ὀρθογώνιος* [right-angled], *ἀμβλυγώνιος* [obtuse-angled], *ὀξυγώνιος* [acute-angled], *ἑτερομήκης* [oblong], *ῥόμβος* [rhombus], *τραπέζιον* [trapezia], *ἐκβάλλω* [produce], *τμῆμα κύκλου* [segment of a circle], *περιγράφεσθαι περὶ* [circumscribed around] and *ἐναρμόζεσθαι* [fitted into]. It will not come as a surprise to readers familiar with early modern geometrical writing that the terms for these plane shapes and relationships were unstable; the confusion around rectangle and oblong persists to the present in English, as does that around trapezium. The instability of this area of vocabulary is compounded by the more general instability of Germanic terms: several terms have three or four distinct versions in German and/or Dutch, though all show at least minimal instability in Latin as well, and there are pockets of high variation among the Romance languages (there are six ways to say *ἐναρμόζεσθαι* [fitted into] in French, for instance). Conversely, minimal variation is shown by *ὀρθός* [right as in right angle], *πλευρά* [side], and *ὕψος* [height]. The first two vary in German only, the last only in English.

For the subject of irrational lines (*i.e.* book 10), Spanish and German are unrepresented in this period. Dutch displays variation for every term, and Latin for a majority. The terms *ἐκ δύο ὀνομάτων* [binomial] and *ἀποτομή* [apotome] vary in every language where they appear, *ἀσύμμετρος* [incommensurable] and *δυνάμει σύμμετροί* [commensurable in power] in Dutch only.

For logical and structural terms, German and Dutch show variation for every term, and the terms *αἰτήματα* [postulates] and *κοιναὶ ἔννοιαι* [common notions] show variation in every language. The latter term was already very unstable in Latin, with six different choices. No term shows variation in fewer than two languages (the variation in these cases is always in Dutch and one of the other Germanic languages). It should also be acknowledged that the *concepts* of axiom, postulate, petition, common notion and indeed definition were important topics of discussion among mathematicians and philosphers in this period, with Euclidean editors differing very widely as to what should be defined and/or assumed but also what was meant by those categories (de Risi, 2016). This is an area, therefore, of not just lexical but conceptual instability, and arguably not directly comparable to the variation in the strictly geometrical

Table 13
Rates of innovation by subject.

Subject	Languages showing variation for a given term (%)	Terms with variation in more than half of languages (%)
Number theory	29	13
Solid geometry	47	19
Plane geometry	63	59
Irrational lines	56	55
Logical/structural	53	40
Ratio and proportion	75	85

terms where it is much clearer that the underlying concepts are shared by different editors and translators.

Finally, by both measures the most variation appears in the terms of book 5, concerning ratio and proportion. Of twenty terms, seventeen show variation in a majority of languages, eight in all languages. The eight are *μέγεθος* [magnitude], *λόγος* [ratio], *ἀναλογία* [proportion], *ὁμόλογα* [corresponding], *ἐναλλάξ* [alternate], *ἀνάπαλιν* [inverse], *σύνθεσις* [composition] and *δι᾽ ἴσου* [ex aequali]. This is another area of vocabulary affected by confusions and hesitations that continue to the present and whose origins are relatively visible and well known. For *λόγος* [ratio] and *αναλογία* [proportion], the possibly confusing pair of Latin equivalents *proportio* and *proportionalitas* goes back at least to Boethius. Zamberti in 1505 replaced them with *ratio* and *proportio*, thereby introducing an ambiguity into the word *proportio* which was inherited by most of the vernacular languages considered in this study: in English at least it persists to the present. Furthermore, *διπλάσιος* [duplicate] and *τριπλάσιος* [triplicate] were rendered variously in Latin, either as *dupla/tripla* or (to make a distinction between relationships of numbers or magnitudes and those of ratios) as *duplicata/triplicata* (see Sylla, 1984): this, too, carried over into nearly every vernacular language. The terms in this book which show variation in only one language are those not specific to its subject matter: *(λόγου) ἔχειν* [to have a ratio] and *μείζων* [greater].

5. Work points

This study has shown that lexical instability in the Euclidean tradition of the sixteenth and seventeenth centuries was distributed unevenly across languages and semantic areas, and it has reported with some granularity where the pockets of higher and lower instability were located. This concluding section draws attention to two questions that have not been asked, and notes certain further questions that might be addressed in future work.

First, the question of cognacy between closely related languages has not been addressed here; neither has the occurrence of similar or identical terms in multiple languages as loans from Latin or Greek: thus in the cross-language work it may be argued that certain terms have been repeat-counted: *κύβος* [cube] for instance translated as *cubus* (Latin), *cubo* (Italian), *cube* (French), *cubo* (Spanish) or *cube* (English); or the pair *scherpe* (Dutch) and *scharpff* (German). But it would require a much finer-grained study of the sources of each item of Euclidean vocabulary to disentangle whether such cases do or do not represent independent choices made by different translators. The fact that these terms are cognates does not by itself imply dependence between translators in different languages; and in nearly all cases specific information is lacking about the sources consulted by any given translator. It is for this reason that this study has focussed attention on cases where translators differed from their predecessors within a given language. For this purpose, in other words, *lemma* in Italian and *lemma* in English represent distinct and at least potentially independent choices by their respective translators.

Second, and setting aside the question of translators' mutual independence, it is tempting to ask how frequently translators adopted loanwords from Greek and/or Latin. Unfortunately any attempt to do so founders, for two reasons. First, a high proportion of the Latin terms in question are either cognates of their Greek equivalents or loans from Greek, the loan having (first) taken place at usually undiscoverable dates from the classical period to the sixteenth century: *κέντρου/centrum, διάμετρος/diametrus, ἰσοσκελής/isosceles* and many more. Thus it is effectively impossible, and not necessarily meaningful, to determine whether, say *cylindre* in Dutch is a loan from Latin (*cylindrus*) or from Greek (*κύλινδρος*). Second, a similar situation exists within the Romance languages: a high proportion of terms are of course cognates of their Latin equivalents (*il ponto, la linea, retta* …), and it is difficult if not impossible to discover – for terms whose earlier history is not easily visible – whether they entered their vernacular language early (as descendants/cognates) or late (as loans). The large number of French words entering Anglo-Saxon/English from the eleventh century onwards effectively extends this problem to English.

Finally, it would be desirable to extend this work in a number of ways. First, the very brief discussion of medieval Latin texts in §3 raises the natural question of whether an approach similar to the present one would be revealing about the Latin geometrical vocabulary in the middle ages. The problems here are complex, since in a manuscript culture the inter-visibility of texts is more the exception than the rule, and much more emphasis must fall on traditional studies of source relationships. Furthermore, a high proportion of the Latin geometrical vocabulary pre-dates the twelfth- and thirteenth-century translations of the *Elements*, yet the date and authorship of the pseudo-Boethian *Geometria* are uncertain.

A different extension would be to a fuller set of early modern printed Latin texts. The present study claims exhaustive coverage of the actually distinct vernacular versions of the *Elements* for its period, but not for Latin versions. It is virtually certain that the Latin versions not contained in this sample (that of Ramus, to name one of the most important) will turn out to contain at least a few vocabulary choices not visible here. It may well be that an exhaustive collation of the Latin texts would not change the overall patterns seen here, but the only way to find out is to carry out the work, which would also be of value for establishing a more reliable classification of the early modern Latin texts than that presented by Wardhaugh *et al.* (2020).

Third and finally – setting aside the obvious extension of the present work to eighteenth-century texts, which in the present state of Euclidean cataloguing is simply not feasible – it might be of value to perform more focussed investigations of the trajectories of particular items of vocabulary or groups of items through this corpus of texts. To some degree the data assembled for this study would facilitate such work. Consider the translation of *ῥόμβος* [rhombus], for instance. Through the data tables for this study it is possible to track the naturalization of transliterations (*rombos, rhombus, rombo, rhombe*) in various languages, the slow demise of Adelard's *elmuain* (last seen in Guzman's 1637 Spanish text), and the more or less successful creation of the vernacular equivalents *diamonde* (1570), *geschrägte vierung* (1610), *ruit* (1617), *losange* (1677), and *geschobene Vierung* (1694). Supplemented by information from appropriate textual corpora, a 'word history' could be assembled. For more conceptually distinctive or disputed terms such as logical or ratio-theory items, such a history might have value to the history of ideas.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.hm.2024.07.002.

Appendix 1. Texts collated

Greek

Stamatēs, Euangelos S., Euclidis Elementa post I. L. Heiberg edidit E. S. Stamatis (Leipzig, 1969–1977).
Grynaeus, Simon, ΕΥΚΛΕΙΔΟΥ ΣΤΟΙΧΕΙΩΝ ΒΙΒΛ. ΙΕ΄ (Basel, 1533).

Latin

Ratdolt, Erhard, Preclarissimum opus elementorum Euclidis megarensis (Venice 1482).
Zamberti, Bartolomeo, Euclidis megarensis philosophi platonicj Mathematicarum disciplinarum Ianitoris (Venice 1505).
Lefèvre d'Étaples, Jacques, CONTENTA. EVCLIDIS Megarensis Geometricorum elementorum libri XV (Paris 1516). de Mondoré, Pierre, Euclidis elementorum LIBER DECIMVS (Paris 1552). [Standing for the edition of 1551.]
Magnienus, Ioannes and Stephanus Gracilis, EVCLIDIS ELEMENTORVM LIBRI XV (Paris 1557).
Dasypodius, Conrad, ΕΥΚΛΕΙΔΟΥ ΤΩΝ ΠΕΝΤΕ ΚΑΙ ΔΕΚΑ ΣΤΟΙΧΕΙΩΝ, ΕΚ ΤΩΝ ΤΟΥ ΘΕΩΝΟΣ συνουσιῶν τὸ πρῶτον (Strasbourg 1564).
Dasypodius, Conrad, ΕΥΚΛΕΙΔΟΥ ΤΩΝ ΠΕΝΤΕ ΚΑΙ ΔΕΚΑ ΣΤΟΙΧΕΙΩΝ ΕΚ ΤΩΝ ΤΟΥ ΘΕΩΝΟΣ συνουσιῶν τὸ δεύτερον (Strasbourg 1564).
Dasypodius, Conrad, PROPOSITIOnes reliquorum Librorum Geometriæ Euclidis (Strasbourg 1564). de Foix de Candalle, François, EVCLIDIS MEGARENSIS MATHEMATICI CLARISSIMI ELEMENTA GEOMETRICA, LIBRIS XV (Paris 1566).
Commandino, Federigo, EVCLIDIS ELEMENTORVM LIBRI XV (Pesaro 1572).
Clavius, Christoph, EVCLIDIS ELEMENTORVM LIBRI XV (Rome 1574).
Maurolico, Francesco, D. FRANCISCI MAVROLYCI, ABBATIS MESSANENSIS, Opuscula Mathematica (Venice 1575).
Hérigone, Pierre, CVRSVS MATHEMATICVS (Paris 1634) [Latin text].
Tacquet, Andrea, ELEMENTA GEOMETRIÆ PLANÆ AC SOLIDÆ (Antwerp 1665) [standing for the edition of 1654].
Barrow, Isaac, EUCLIDIS ELEMENTORUM Libri xv. breviter demonstrati (Cambridge 1655).
Gregory, David, ΕΥΚΛΕΙΔΟΥ ΤΑ ΣΩΖΟΜΕΝΑ (Oxford 1703).

Italian

Tartaglia, Niccolò, EVCLIDE MEGARENSE PHILOSOPHO: SOLO INTRODVTTORE DELLE SCIENTIE MATHEMATICE: DILIGENTEMENTE REASSETTATO (Venice 1543).
Cajani, Angelo, I QVINDICI LIBRI DEGLI ELEMENTI DI EVCLIDE, DI GRECO TRADOTTI IN LINGVA THOSCANA (Rome 1545).
Ricci, Giovanni, DE GLI ELEMENTI DI EVCLIDE Li Primi sei Libri Tradotti in lingua Italiana (Bologna 1651).
Caravaggi, Pietro Paolo, I PRIMI SEI LIBRI D'EVCLIDE TRATTI IN VOLGARE (Milan 1671).
Viviani, Vincenzio, ELEMENTI PIANI, E SOLIDI D'EVCLIDE (Florence 1746) [standing for the edition of 1690].

German

Scheybl, Johann, Das sibend, acht und neünt büch, des hochberümbten Mathematici Euclidis Megarensis (Augsburg 1555).
Holtzman, Wilhelm, Die Sechs Erste Bücher Euclidis, Vom anfang oder grund der Geometrj (Basel 1562).
Marius, Simon, Die Ersten Sechs Bücher Elementorum EVCLIDIS (Ansbach 1610).
Curtius, Sebastian, Die sechs ersten Bücher EVCLIDIS (Amsterdam 1618).
Burckhard von Pirckenstein, Anton Ernst, Teutsch-Redender Euclides, Oder Acht Bücher Von Denen Anfängen Der Meß-Künst (Vienna 1694).
Reyher, Samuel, In Teutscher Sprache vorgestellter EUCLIDES (Kiel, Hamburg and Leipzig 1697).

French

Forcadel de Beziés, Pierre, LES SIX PREMIERS LIVRES DES ELEMENTS D'EVCLIDE (Paris 1564).
Forcadel de Beziés, Pierre, LES SEPTIEME, HVICTIEME ET NEVFIEME, LIVRES DES ELEMENS D'EVCLIDE (Paris 1565).
Errard, Jean, LES NEVF PREMIERS LIVRES DES ELEMENS D'EVCLIDE (Paris 1605) [standing for the edition of 1598].
Dounot, Didier, LES ELEMENS DE LA GEOMETRIE D'EVCLIDES MEGARIEN (Paris 1613) [standing for the edition of 1610].
Peletier, Jacques and Jean de Tournes, LES SIX PREMIERS LIVRES DES ELEMENTS GEOMETRIQVES D'EVCLIDE (Geneva 1611).
Henrion, Denis, LES QUINZE LIVRES DES ELEMENTS D'EVCLIDE (Paris 1615).
le Mardelé, Pierre, LES QVINZE LIVRES DES ELEMENTS GEOMETRIQVES D'EVCLIDE MEGARIEN (Paris 1622).
Hérigone, Pierre, CVRSVS MATHEMATICVS (Paris 1634) [French text].

Fournier, Georges, LES ELEMENTS D'EVCLIDE (Paris 1654).
Milliet Dechales, Claude-François, HVICT LIVRES DES ELEMENTS DEVCLIDE (Lyon 1672).
Milliet Dechales, Claude-François, LES ELEMENS D'EVCLIDE (Paris 1677).
Rohault, Jacques and Claude Clerselier, OEUVRES POSTHUMES DE Mr ROHAULT (Paris 1682).
Ozanam, Jacques, COURS DE MATHEMATIQUE … TOME PREMIER. Qui contient l'Introduction aux Mathematiques, & les Elemens d'Euclide (Paris 1693).

English

Billingsley, Henry, THE ELEMENTS OF GEOMETRIE of the most auncient Philosopher EVCLIDE of Megara (London 1570).
Rudd, Thomas, EUCLIDES ELEMENTS OF GEOMETRY: The first VI Books (London 1651).
Barrow, Isaac, EUCLIDE'S ELEMENTS; The whole Fifteen Books compendiously Demonstrated (London 1660).
Leeke, John and George Serle, EUCLID'S ELEMENTS OF Geometry. In XV. Books (London 1661).
Moore, Jonas, A NEW SYSTEME OF THE MATHEMATICKS (London 1680–81).
Hallifax, William (attr.), THE ELEMENTS OF EUCLID (Oxford 1685).
Williams, Reeve, THE ELEMENTS OF EUCLID (London 1685).

Spanish

de Zamorano, Rodorigo, LOS SEIS LIBROS PRIMEROS DELA GEOMETRIA DE EVCLIDES (Seville 1576).
Carduchi, Luis, ELEMENTOS GEOMETRICOS DE EVCLIDES PHILOSOPHO MEGARENSE SVS SEYS PRIMEROS LIBROS (Alcala 1637).
de Nájera, Antonio and Juan de la Rocha (attr.), SEGVNDA PARTE DEL ARTE Y VSO DE ARCHITECTVRA … CON EL QVINTO Y SEPTIMO libros de Euclides traducidos de latín en Romance (Madrid 1665).
Fernandez de Medrano, Sebastian, LOS SEIS PRIMEROS LIBROS, ONZE, Y DOZE DE LOS ELEMENTOS DE EUCLIDES MEGARENSE (Brussels 1688).
Kresa, Jacobo, ELEMENTOS GEOMETRICOS DE EVCLIDES, LOS SEIS PRIMEROS LIBROS DE LOS PLANOS; Y LOS ONZENO, Y DOZENO DE LOS SOLIDOS (Brussels 1689).

Dutch

Dou, Jan Pieterszen, De ses eerste boucken EVCLIDIS (Leiden 1606). van Schooten, Frans, DE PROPOSITIEN vande xv. Boucken der Elementen Euclidis (Leiden 1617). van Nienrode, Cornelis, DE Vijfthien Boecken EVCLIDES (Utrecht n.d.).
Willemszen, Iacob, EVCLIDES ZES EERSTE BOEKKEN (Hamburg 1633).
Vooght, Claas Janszen, EUCLIDIS BEGINSELEN der MEETKONST, Vervaat in 15 Boeken, Waar by't 16 Boek Fr. Flussatis Candallæ (Amsterdam 1695).
Coets, Henrick, DE SES EERSTE BOEKEN DER BEGINSELEN EUCLIDIS (Amsterdam 1702).

Appendix 2. Terms collated

Logical/Structural	*ἀντιπεπουθώς*
ὅρος	*ἄκρος καὶ μέσος (λόγος)* (def. 6.2)
αἴτημα	*ὕψος* (def. 6.3)
κοινὴ ἔννοια	
propositio	Ratio and proportion
problema	*μέγεθος* (def. 5.1)
theorema	*μέρος* (def. 5.1)
πόρισμα (*e.g.* prop. 3.1)	*πολλαπλάσιος* (def. 5.2)
λῆμμα (*e.g.* prop. 10.13)	*λόγος* (def. 5.3)
ὅπερ ἔδει ποιῆσαι	*(λόγου) ἔχω* (def. 5.4)
ὅπερ ἔδει δεῖξαι	*ἐν τῷ αὐτῷ λόγῳ* (def. 5.5)
	ἀναλογία (def. 5.18)
Plane geometry	*ἀνάλογον* (def. 5.6)
σημεῖον (def. 1.1)	*μείζων* (def. 5.7)
γραμμή (def. 1.2)	*διπλάσιος* (def. 5.9)
πέρας (def. 1.3)	*τριπλάσιος* (def. 5.10)
εὐθύς (def. 1.4)	*ὁμόλογα* (def. 5.11)
ἐπιφάνεια (def. 1.5)	*ἐναλλάξ* (def. 5.12)
πέρας (def. 1.6)	*ἀνάπαλιν* (def. 5.13)
ἐπίπεδος (def. 1.7)	*σύνθεσις* (def. 5.14)
γωνία (def. 1.8)	*διαίρεσις* (def. 5.15)
εὐθύγραμμος (defs. 1.9, 19)	*ἀναστροφή* (def. 5.16)

(*continued on next page*)

(*continued*)

ἴσος (def. 1.10)	*δι᾽ ἴσου* (def. 5.17)
ὀρθός (def. 1.10)	*ordinata proportio*
κάθετος (def. 1.10)	*τεταραγμένη (ἀναλογία)* (def. 5.18)
ἀμβλύς (def. 1.11)	*πηλικότητες* (def. 6.4)
ὀξεῖα (def. 1.12)	
ὅρος (def. 1.13)	Number theory
σχῆμα (def. 1.14)	*μονάς* (def. 7.1)
κύκλος (def. 1.15)	*ἀριθμός* (def. 7.2)
κέντρον (def. 1.16)	*ἄρτιος* (def. 7.6)
διάμετρος (def. 1.17)	*περισσός* (def. 7.7)
περιφέρεια (def. 1.17)	*πρῶτος* (def. 7.11)
ἡμικύκλιον (def. 1.18)	*(πρῶτοι, σύνθετοι) πρὸς ἀλλήλους* (def. 7.12)
τρίπλευρος (def. 1.19)	*σύνθετος* (def. 7.13)
τετράπλευρος (def. 1.19)	*τέλειος* (def. 7.22)
πολύπλευρος (def. 1.19)	
πλευρά (def. 1.20)	Irrational lines
τρίγωνον (def. 1.20)	*σύμμετρος* (def. 10.1)
ἰσόπλευρος (def. 1.20)	*ἀσύμμετρος* (def. 10.1)
ἰσοσκελής (def. 1.20)	*δυνάμει σύμμετροι* (def. 10.2)
σκαληνός (def. 1.20)	*ῥητός* (defs. 10.3, 4)
ὀρθογώνιος (def. 1.21)	*ἄλογος* (defs. 10.3, 4)
ἀμβλυγώνιος (def. 1.21)	*μέση* (prop. 10.21)
ὀξυγώνιος (def. 1.21)	*ἐκ δύο ὀνομάτων* (prop. 10.36)
τετράγωνον (def. 1.22)	*ἐκ δύο μέσων* (prop. 10.37)
ἑτερομήκης (def. 1.22)	*μείζων* (prop. 10.39)
ῥόμβος (def. 1.22)	*ἀποτομή* (prop. 10.73)
ῥομβοειδής (def. 1.22)	*ἐλάσσων* (prop. 10.76)
τραπέζιον (def. 1.22)	
παράλληλος (def. 1.23)	Solid geometry
ἄγω (post. 1)	*στερεός* (def. 11.1)
ἐκβάλλω (post. 2)	*πέρας* (def. 11.2)
γράφω (post. 3)	*κλίσις* (defs. 11.5, 6)
βάσις (prop. 1.5 enunciation)	*στερεὰ γωνία* (def. 11.11)
παραλληλόγραμμον χωρίον (prop. 1.34 enunciation)	*πυραμίς* (def. 11.12)
παραλληλόγραμμον (def. 2.1)	*πρίσμα* (def. 11.13)
περιέχω (def. 2.1)	*σφαῖρα* (def. 11.14)
γνώμων (def. 2.2)	*ἄξων* (defs. 11.15, 19, 22)
ἐφάπτω (defs. 3.2, 3)	*κῶνος* (def. 11.18)
(ἴσος) ἀπέχω (def. 3.4)	*κύλινδρος* (def. 11.21)
τμῆμα κύκλου (def. 3.6)	*κύβος* (def. 11.25)
βαίνω (def. 3.9)	*τετράεδρον*
τομεύς (def. 3.10)	*ὀκτάεδρον* (def. 11.26)
ὅμοιος (def. 3.11)	*εἰκοσάεδρον* (def. 11.27)
ἐγγράφω (defs. 4.1, 3, 5)	*δωδεκάεδρον* (def. 11.28)
περιγράφω περί (defs. 4.2, 4, 6)	*στερεός παραλληλεπίπεδος* (prop. 11.25)
ἐναρμόζω (def. 4.7)	

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