STEP Examiners' Report 2016

Mathematics

STEP 9465/9470/9475

November 2016

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STEP Mathematics (9465, 9470, 9475)

STEP I 2016 REPORT

General Comments

This year, more than 2000 candidates signed up to sit this paper, though just under 2000 actually sat it. This figure is about the same as the entry figure for 2015, though the number of candidates opting to sit STEP I has risen significantly over recent years; for instance, it was around 1500 in 2013.

There is no doubt that the purpose of the STEPs is to learn which students can genuinely use their mathematical knowledge, skills and techniques in an arena that demands of them a level of performance that exceeds anything they will have encountered within the standard A-level (or equivalent) assessments. The ability to work at an extended piece of mathematical work, often with the minimum of specific guidance, allied to the need for both determination and the ability to "make connections" at speed and under considerable time pressure, are characteristics that only follow from careful preparation, and there is a great benefit to be had from an early encounter with, and subsequent prolonged exposure to, these kinds of questions.

It is not always easy to say what level of preparation has been undertaken by candidates, but the minimum expected requirement is the ability to undertake routine A-level-standard tasks and procedures with speed and accuracy. At the top end of the scale, almost 100 candidates produced a three-figure score to the paper, which is a phenomenal achievement; and around 250 others scored a mark of 70+, which is also exceptionally impressive. At the other end of the scale, over 400 candidates failed to reach a total of 40 marks out of the 120 available.

For STEP I, the most approachable questions are always set as Qs. 1 & 2 on the paper, with Q1 in particular intended to afford every candidate the opportunity to get something done successfully. So it is perfectly reasonable for a candidate, upon opening the paper, to make an immediate start at the first and/or second question(s) before looking around to decide which of the remaining 10 or 11 questions they feel they can tackle. It is very important that candidates spend a few minutes – possibly at the beginning – reading through the questions to decide which ***six*** they intend to work, since they will ultimately only be credited with their best six question marks. Many students spend time attempting seven, eight, or more questions and find themselves giving up too easily on a question the moment the going gets tough, and this is a great pity, since they are not allowing themselves thinking time, either on the paper as a whole or on individual questions.

The other side to the notion of strategy is that most candidates clearly believe that they need to attempt (at least) six questions when, in fact, four questions (almost) completely done would guarantee a Grade 1 (Distinction), especially if their score on these first four questions were then to be supplemented by a couple of early attempts at the starting parts of a couple more questions (for the first five or six marks); attempts which need not take longer than, say, ten minutes of their time. It is thus perfectly reasonable to suggest to candidates, in their preparations, that they *can* spend more than 30 minutes on a question, but only IF they think they are going to finish it off satisfactorily, although it might be best if they were advised to spend absolutely no more than 40-45 minutes on any single question; if they haven't finished by then, it really is time to move on.

Curve-sketching skills are usually a common weakness, but were only tested on this paper in Q3. The other common area of weakness – algebra – was tested relatively frequently, and proved to be as testing as usual. Calculus skills were generally "okay" although the integration of first-order differential equations by the separation of variables, as appearing repeatedly in Q4, was found challenging by many of the candidates who attempted this question. The most noticeable deficiency, however, was in the widespread inability to construct an argument, particularly in Qs. 5, 7 & 8. Vectors are often poorly handled, and this year proved no exception.

Comments on individual questions

[Examiner's note: in order to extract the maximum amount of profit from this Report, it is firmly recommend that the reader studies it alongside the *Solutions* and/or *Mark Scheme* supplied separately.]

Question 1

Marginally the most popular question on the paper, and the highest-scoring, this was a relatively carefully signposted question; thus, even though the demands were entirely algebraic, it was a good starter question and gave all candidates something to get their teeth into. It was still often the case that candidates spent a lot more time doing fairly simple things than they should have; for instance, an awful lot of attempts produced over and over again (effectively) the same work to show that $\frac{x^{2n+1}+1}{x+1} \equiv x^{2n} - x^{2n-1} + \ldots + x^2 - x + 1$ in each of the four given cases. And a similar amount of unnecessary effort was expended on what should have been some fairly simple binomial expansions. Nevertheless, most candidates made good progress for the *n* = 1, 2, 3 cases.
To show that p_4 and q_4 are not identical, it suffices to choose any one value of x for which they yield different outputs, but most approaches preferred to deal with the full polynomial expansions, which is fine but (again) not an optimal approach.
In part (ii), most candidates realised that they were to use the results of part (i), and they were generally able to do so for at least (a). Relatively few realised that the same idea (the use of *the difference of two squares factorisation*) was to be deployed in (b), presumably put off by the large numbers involved and the notion that the answer could be left in terms of powers of 7.

Question 2

This was the second most popular question of all, attempted by over 80% of candidates, though pulling in a mean score of just under half-marks. Most candidates managed the tricky differentiation; tricky, since it required the repeated use of the *Chain* and *Product* rules of differentiation. The big key to later progress in this question was the success, or otherwise, of the simplifying that was done. Those who realised that $\sqrt{1+x^2}$ needed to be re-written as $\frac{1+x^2}{\sqrt{1+x^2}}$ flew through the simplification, and this made the idea behind the three later parts much more transparent. In fact, careful differentiation and a sound simplification made choosing the appropriate values of the given constants *a* to *e* straightforward.

Question 3

It was very encouraging, on this question, to see both the number of attempts (only a few behind those for Qs.1 & 2) and the quality of them. The introduction of a new function is frequently a guarantee of poor answers, especially when it is made to act on another function (the sine function here), but many candidates seemed to cope quite well with the "int" function and the properties of its "step" graphs. Although reminded (at the end of the question) to make the endpoints of the steps completely clear, there was a lot of vagueness in candidates' answers on these points, and this was one of the principal causes of lost marks. An overall mean score of just over 12½ out of 20 is testimony to the overall success on this potentially tricky question.

Question 4

Around 60% of candidates attempted this question, but the mean score achieved on it was under 3½ out of 20. The first three marks were awarded for a correct differentiation and subsequent simplification (of a very similar kind to that in Q2 but much, much easier), but it is clear that almost no-one was able to proceed further into the question, due almost entirely to difficulties working with $\frac{\mathrm{d}y}{\mathrm{d}x}$ as an entity in its own right (along with *its* derivative, $\frac{\mathrm{d}^2 y}{\mathrm{d}x^2}$). This is especially disappointing, since this is little more than a labelling matter. Even for those who did see what to do in that respect, spotting that one then had a separable-variable 1^{st}-order d.e. to deal with proved difficult.

Question 5

Attempts at this question were down to around a third of the candidature and, overall, it proved to be the lowest scoring question on the paper with a mean score of just 3 out of 20. The big problem here was the widespread inability to draw some suitable lines onto the diagram, or to realise that the lines joining the centres necessarily passed through the points of contact. Once this is done, there is an obvious right-angled triangle to be found embedded within this geometric arrangement that then requires only the use of *Pythagoras' Theorem* to make a start.

Although there were relatively few complete efforts to be found, many who did manage to make a good start found aspects of the algebra difficult: for instance, turning result (*****) into (******). Here, there are several good approaches provided one uses (*****) sensibly to eliminate (say) b.

Admittedly, the last part to the question *was* more demanding to deal with, but it was clear from responses that the majority of even those candidates who got this far struggled to see the logical difference between proving $A \Rightarrow B$ and proving $B \Rightarrow A$.

Question 6

This vectors question proved both unpopular and low-scoring, being attempted by only 30% of candidates and eliciting a mean score of only 5 out of 20. Once again, it was clear that candidates were, in general, doing little more than making a half-hearted attempt at the very first part of the question. The rest of the question relied only on the ability to write the vector equations of pairs of lines and then solve simultaneously by considering the coefficients of **a** and **b**. Overall this question suggests that vectors are not well understood.

Question 7

This was a rather splendid reasoning question, and many candidates responded very well to its demands. Almost half of all candidates made an attempt at it, achieving a mean score of over 7 out of 20. Whilst many attempts went little beyond the first two parts, many candidates actually did well on the question as a whole.

Part (iii) required a mixture of a proof by contradiction based on at least an informal understanding of the method of proof by induction, so it was no surprise that many gave up at this stage. The "fun" part was (v), in which candidates had to choose some numbers that demonstrated the required properties; unfortunately, it is clear this sort of request is not always well answered.

Question 8

Generating functions generally appear very late on in statistics modules whose entry numbers seldom reach three figures. Nevertheless, a mean score of almost 9 out of 20 on this question, obtained by more than a quarter of the candidates (very few, if any, of whom will have seen the idea before), suggests that it is easy to introduce the topic and that good candidates will pick it up quickly and successfully.

Apart from algebraic difficulties, the real hurdle to making a complete attempt lay in part (ii) (a); although most of the candidates who got this far went on to earn the 4 marks allocated to this part, they tended to do so by ignoring the guidance of the question. Although there are two or three perfectly good alternative approaches to the one intended, they don't necessarily point in the direction that helps the solver cope with the more imaginatively constructed part (ii) (b); and this was why most candidates struggled to know quite what to do with it.

Questions 9, 10 & 11

The three mechanics questions each received a healthy number of "hits" this year, and marks were fairly respectable also.

Question 9

In this questions – a statics question – candidates were helped enormously by the given diagram, which allowed most takers the opportunity to get most of the preliminary "force" statements down correctly: resolving twice and taking moments (choosing sensible directions and a suitable axial point), along with the straightforward use of the "$F = \mu R$" friction law, meant that 7 marks could be obtained simply for noting all the correct ingredients. Suitable choices for eliminating terms would then lead to the printed answer with little difficulty beyond the algebraic. It is fair to say, however, that the prospect of doing it all again for the second configuration proved too much for many candidates, although it actually only involved the realisation that certain forces changed directions and could thus be replaced by their negatives.

Question 10

This question was a relatively undemanding collisions question, a fact that was apparent to a lot of the candidates, almost half of whom made an attempt at the question. It turned out to be only one of three questions on the paper for which the mean achieved mark was over 10 out of 20 (after Qs. 1 & 3), and this is no doubt partly due to the fact that there are generally only three physical "laws" or "principles" to be applied on this type of mechanics problem. On this occasion, no energy considerations were involved, which meant that careful application of *Conservation of Linear Momentum* and *Newton's (Experimental) Law of Restitution* pretty much saw the solver through the whole thing. The only minor hurdle is that candidates often get confused about which directions are being taken as positive, and this is usually down to the lack of a suitably-marked diagram. Other than that, it was only a few algebraic slips here and there that prevented full and successful attempts from being made.

Question 11

This question was also a rather pleasant question of its kind, dealing with projectile motion. It proved to be a very popular question (with 40% of all candidates attempting it, almost as popular as Q10) but with a mean score of almost 8 out of 20. There were two main obstacles to progress in this question: first, rather a lot of candidates failed to appreciate that finding the greatest something-or-other might require calculus; secondly, and more importantly, putting everything together to create a quadratic in $c = \cos 2\alpha$ proved challenging.

Question 12

This question proved to be an especially popular choice (almost 45% uptake) and a high-scoring one at that (mean score of over 9 out of 20). However, most of these medium-successful marks came from attempts at the first two (specific) cases, in which Bob threw 2 coins, then 3. There were 6 marks for successful attempts at each of these preliminary parts, and candidates were happy to work them through reasonably successfully, although some of these attempts were very poorly explained; and occasionally it was the case that there was no explanation at all. Although they may have been getting the correct answers, it is imperative to ensure that answers are sufficiently coherent for the reader to be able to follow their reasoning and/or structure and hence understand how the answers have been arrived at.

The final part of Q12 elicited little more than a few half-efforts at the general situation, but the general reasoning required proved beyond most candidates. A small number of candidates thought they were being asked for an inductive proof of some kind, using parts (i) and (ii) as base-line cases.

Question 13

This attracted the smallest amount of attention: 83 attempts, with a mean score of 5 out of 20. Candidates should recognise the (negative) exponential distribution here, and many candidates did so. It is thus a question about pdfs and cdfs and multiplying the probabilities of independent events. The only commonly scored marks were those for the expectation, gained using integration by parts. Almost no candidates made it to part (ii).

STEP II 2016 REPORT

General Comments

As in previous years the Pure questions were the most popular of the paper with questions 1, 3 and 7 the most popular of these. The least popular questions of the paper were questions 10, 11, 12 and 13 with fewer than 400 attempts for each of them. There were many examples of solutions in this paper that were insufficiently well explained, given that the answer to be reached had been provided in the question.

Comments on individual questions

Question 1
This was a popular question and many very good solutions were seen. The first part of the question was a relatively straightforward application of differentiation and parametric equations and was successfully completed by many of the candidates. The sketches produced were generally the correct shape for the parabola, although in some cases it was not in the correct position. The other curve caused more problems with some candidates drawing another parabola or similar shape.

Question 2
This question received poor responses in terms of the average mark per attempt. Application of the factor theorem to the first part often produced a neat solution. However, a number of candidates in the first part did not use the factor theorem as requested and so produced very complicated algebraic expressions that were more of a challenge to simplify. Where the result had been successfully shown and the expression factorised, many candidates were able to see the relevance to solving the equation in part (i). Those candidates who were able to follow through the method to successfully factorise the second expression were often able to complete the question.

Question 3
This was the most popular question on the paper, and candidates generally scored well here. The first two parts were relatively straightforward and were answered well. The final part required careful explanation from candidates and many were not able to take the initial step of rewriting the relationship between the function and its derivative in a useful way. Those who did successfully complete this part were often able to identify the number of roots in each of the two cases.

Question 4
This question attracted many good responses which often successfully accomplished the first and third results of part (i) of the question, although in many cases marks were lost through incomplete explanations of some of the steps taken. Part (ii) of the question was generally answered poorly with some candidates simply stating that the square root of one expression in terms of surds was equal to the other one that they had achieved. Only a small number of candidates successfully completed the last section of this question.

Question 5
This was the least attempted of all of the Pure questions and one that generally produced low marks for candidates, who generally appeared to have difficulty in expressing the coefficients of the binomial expansion in the required form. In each case the desired answer was given in the question, and so successful solutions also needed to be very clear about the reasoning used to reach the answer.

Question 6
This question was answered relatively poorly compared to the others, as many candidates did not appear to read the question carefully enough and so attempted to solve the differential equations in parts (i) and (ii) rather than simply verifying the results given. Where candidates moved on to parts (iii) and (iv) they were generally successful if they were able to complete the differentiation of the new function.

Question 7
This was the second most popular and one of the best-answered questions on the paper, with many candidates scoring very high marks. In many cases the initial result was explained clearly and then applied successfully to the first example. Candidates were generally able to follow through the calculations where they were able to see the way in which the result could be achieved, and so most of the attempts that followed a correct method only lost marks through occasional errors in calculation.

Question 8
The first task in this question was generally well answered, although sketches were often unclear or difficult to interpret. In part (i) many candidates were able to obtain the first approximation, but then could not see how to achieve the other two, often offering sums of a non-integer number of terms which gives the correct approximation when substituted into the formula. Those who successfully completed part (i) were often able to approximate the error in part (ii) and see how it applies to the final sum.

Question 9
This question was the most popular of the mechanics questions, and many candidates were able to complete the first part of the question successfully. In many cases this was as far as they got, as a large number of candidates were unable to make significant progress on part (ii). Where candidates were able to identify a correct strategy for solving the problem they were often successful in reaching expressions, only losing marks through errors in the algebra.

Question 10
This question received a number of very good, and often concise, answers. However, there was a significant number of candidates who did not calculate the centre of mass, or mistakenly assumed that the formula for the centre of mass for an equilateral triangle could be applied. Many candidates chose to consider the limiting case first and then deduce the inequality in the final step, but did not justify the direction of the inequality clearly. There were a number of cases where the required angles where not calculated correctly when resolving the forces.

Question 11
Although not a popular question, this was one of the better-answered questions in terms of the average number of marks achieved per candidate. Many candidates who attempted this question were able to gain many of the marks for part (i), often by substituting $\tan\theta$ for $\frac{b}{a}$ into the simultaneous equations and then eliminating t. Some candidates, however, lost some marks for assuming that $a = \cos\theta$ and $b = \sin\theta$. Part (ii) was well answered by many candidates, but very few solutions successfully explained the link between the two parts of the question.

Question 12
The first part of the question required the proof to follow from the result quoted in the question. For this reason, solutions that explained the result by drawing a Venn diagram were not awarded full marks. In many cases, sets needed to be more clearly defined (for example $A \cap B \cup C$). This was again an example of a question with a given answer where many candidates did not fully explain all of the steps in the proof. The result for the union of four sets was generally well answered, although there were several answers in which not all of the pairwise intersections were identified.
Many candidates were able to calculate the probabilities required in parts (i), (ii) and (iii), but few were able to apply the results from the start of the question to the final calculations.

Question 13
This question received only a small number of attempts, with a significant number of candidates not identifying that a rectangle could be used to approximate the area in each of the cases and so unable to make much progress on the question. The average mark per candidate for this question was the lowest on the paper, with a significant number of attempts not progressing beyond the first step.

STEP III 2016 REPORT

General Comments

A substantially larger number of candidates took the paper this year: 14% more than in 2015. However, the mean score was virtually identical to that in 2015. Five questions were very popular, with two being attempted by in excess of 90% of the candidates, but once again, all questions were attempted by significant numbers, with only one dipping under 10% attempting it, and every question was answered perfectly by at least one candidate. Most candidates kept to six sensible attempts, although some did several more scoring weakly overall, except in six outstanding cases that earned very high marks.

Comments on individual questions

Question 1

This was the most frequently attempted question with more than 93% of candidates attempting it. It was also successfully attempted, the second most in this respect and only by a small margin, earning two thirds marks on average. The majority of candidates completed parts (i) and (iii) with little trouble, with various algebraic mistakes occurring throughout, and a few candidates forgetting to substitute for the limits in part (i). Many got started on part (ii) using the substitution from part (i), and then get stuck faced with the consequent integral.

Question 2

This question was quite popular, being attempted by just over three-quarters of the candidates, but success was moderate. Most got underway differentiating implicitly, rather than parametrically, and were able to find equations of tangents, normal and chords, but not always simplifying by factorising to make their lives easier; those who could factorise made good progress, whilst those who did not struggled to find (i). Other weaknesses were not appreciating that they could find $r+q$ and rq, which then led to not finding the certain point in (ii). In the final part, square rooting the inequality and only considering the positive case was not uncommon.

Question 3

Marginally less popular than question 2, this was very slightly better attempted. In both parts, candidates successfully equated the differential of the expressions on the right of the equations to the expression to be integrated, with the exponential function cancelled. In the first part, many obtained $P(x)$ in the given case of $Q(x)$, but the attempted proofs that the degree of $P(x)$ is one more than that of $Q(x)$ and for part (ii) that no such polynomials exist led to many illogical steps. Many would have benefited by multiplying up by denominators and using the remainder/factor theorem, rather than attempting arguments based on degrees of rational expressions. Some subverted part (i) by successfully integrating the first expression.

Question 4
Very slightly more popular than question 2 with four fifths attempting it, they did so with slightly less success. The first part of the question, being well signposted, was pretty well attempted, although there was some very poor notation for limit arguments as N was commonly taken to equal infinity. In part (ii), it was quite common for candidates to write the expression for sech(ry) in terms of positive powers of exponentials which made attempts to apply (i) invalid. Few candidates fully simplified the final result, and prior to that, many did not handle the positive and negative parts of the sum correctly with some just doubling the sum from 1 to infinity.

Question 5
This was attempted by half the candidature, scoring similarly to question 2. The binomial expansion and its symmetry were well-handled in the first part, as was applying the result of (iii) in part (iv). Part (ii) was not well-answered as there tended to be cavalier statements regarding divisibility, and in part (iii), few noticed that the condition $\mathrm{m} + 1 \leq 2\mathrm{m}$ was required in order to use (ii).

Question 6
Just under 40% attempted this question, and did so without great success, scoring about one-third marks. The majority knew the formula for cosh of a sum, or if not, could use definitions and compare coefficients to obtain the first result in the stem. However, they were very weak on the $\mathrm{A} = \mathrm{B}$ case.
Explanation for part (i) was poor, and the plus or minus was frequently not properly understood; as a consequence, a specious plus or minus often appeared in part (ii). Arguing necessary and sufficient conditions in (iii) and (iv) was weak. However, a small number of good candidates did complete this question.

Question 7
This was the least popular question in the Pure section of the paper being attempted by less than 30% of the candidates, and whilst there were some very good solutions, the standard of attempts was generally not good, and in fact, only one of the Mechanics questions was less well-answered in the whole paper. In general, the stem was pretty well answered, but even here, having appreciated that each factor on the LHS was a factor of the RHS, frequently there was no consideration given to the, admittedly simple to obtain, scalar factor being one. In spite of the stem, most did not appreciate how to proceed with part (i), and so went little further.

Question 8

Attempted by nearly as many as attempted question 1, it was marginally more successful, and a good number achieved full marks. Generally, the idea of repeatedly applying a function to create a cycle was well-spotted. However, candidates did sometimes fall down trying to find $g(x)$ in (ii) and some substituted the given $g(x)$ rather than finding it. In part (iii), some stopped having made the first substitution and so could not find the solution. Also, some guessed the solution for part (iii) but, of course, this did not do the full job.

Question 9

Although not overly popular, being attempted by less than a fifth of candidates, this question was moderately successful, a little better than question 3. Finding the extensions and tension in the first two parts of the question was completed by most candidates, but having generally written down the equation of motion, very few thought of applying the binomial expansion and so could not proceed to the final result.

Question 10

One of the least popular questions, being attempted by about a seventh of the candidates, it was the least successfully answered with just under quarter marks scored. As ever, there were some very strong solutions. Generally, the first result of the question was done well as they could resolve accurately and identify the condition, > 0 . For the final result, not many identified the condition$T > 0$, and so could not proceed. Generally, energy was conserved well, though some omitted one or other of the kinetic energy terms. As far as circular motion was concerned, some treated the radius as a rather than $\cos\beta$.

Question 11

The most popular of the non-Pure questions, it was attempted by a third of the candidates, but generally, only about a quarter of the marks were scored. A large number attempted to use constant acceleration formulae, or if they realised that calculus was required, failed to appreciate that they needed to use “$a = v\,dv/dx$" . For those that separated variables, the integrations caused few problems. Part (iii) caused difficulties as candidates were not comfortable using the bounds; had they considered $\lambda X_1 - \lambda X_2$ they might have encountered fewer problems.

Question 12

Whilst as popular (or rather unpopular) as question 10, attempts at question 12 were more successful than all but questions 1 and 8 with on average half marks being scored. Part (i) was generally well done using the binomial distribution, and those that spotted they should use the Poisson distribution in part (ii) usually did well too. However, candidates were often sloppy in their explanations of the rearrangements of Chebyshev, and also quite often candidates had a fixation with the Normal distribution which did not help.

Question 13
This was the least popular question being attempted by only half the number attempting question 12, and with slightly less success than for question 11. Most candidates picked up a few marks at the start of the question and then a small number used integration by parts in (i), but others attempted this unsuccessfully trying integration by change of variable. The multiplication of T^4 was surprisingly badly done, and the expectation of a constant being zero was similarly surprisingly common.

Explanation of Results STEP 2016

All STEP questions are marked out of 20. The mark scheme for each question is designed to reward candidates who make good progress towards a solution. A candidate reaching the correct answer will receive full marks, regardless of the method used to answer the question.

All the questions that are attempted by a student are marked. However, only the 6 best answers are used in the calculation of the final grade for the paper.

There are five grades for STEP Mathematics which are:
S – Outstanding
1 – Very Good
2 – Good
3 – Satisfactory
U – Unclassified

The rest of this document presents, for each paper, the grade boundaries (minimum scores required to achieve each grade), cumulative percentage of candidates achieving each grade, and a graph showing the score distribution (percentage of candidates on each mark).

STEP Mathematics I (9465)

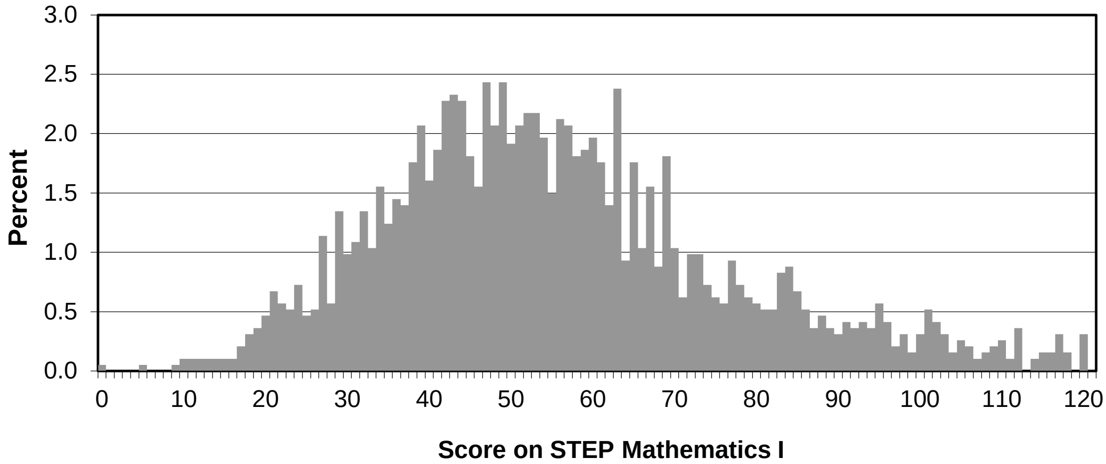
Grade boundaries

Maximum Mark	S	1	2	3	U
120	102	75	60	41	0

Cumulative percentage achieving each grade

Maximum Mark	S	1	2	3	U
120	3.7	17.2	37.0	75.7	100.0

Distribution of scores



STEP Mathematics II (9470)

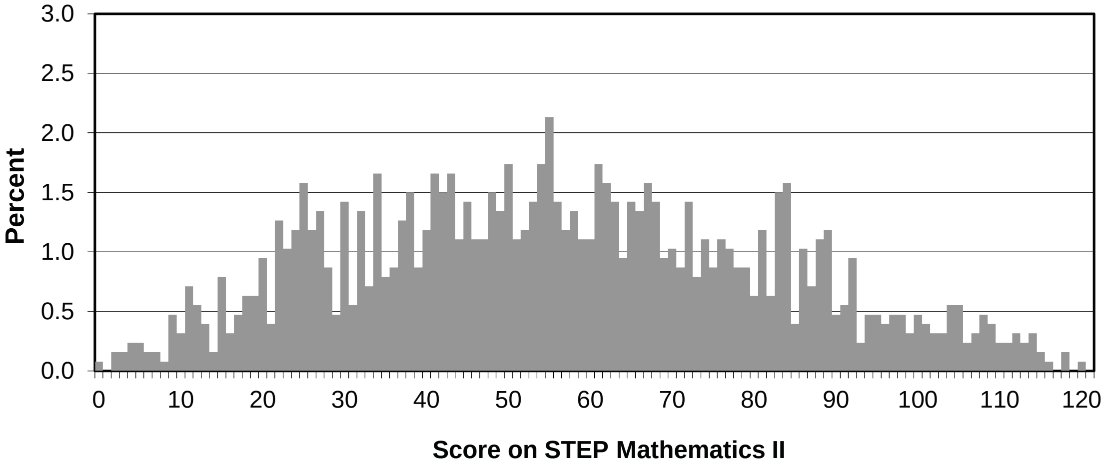
Grade boundaries

Maximum Mark	S	1	2	3	U
120	95	74	65	31	0

Cumulative percentage achieving each grade

Maximum Mark	S	1	2	3	U
120	8.0	26.5	37.3	81.6	100.0

Distribution of scores



STEP Mathematics III (9475)

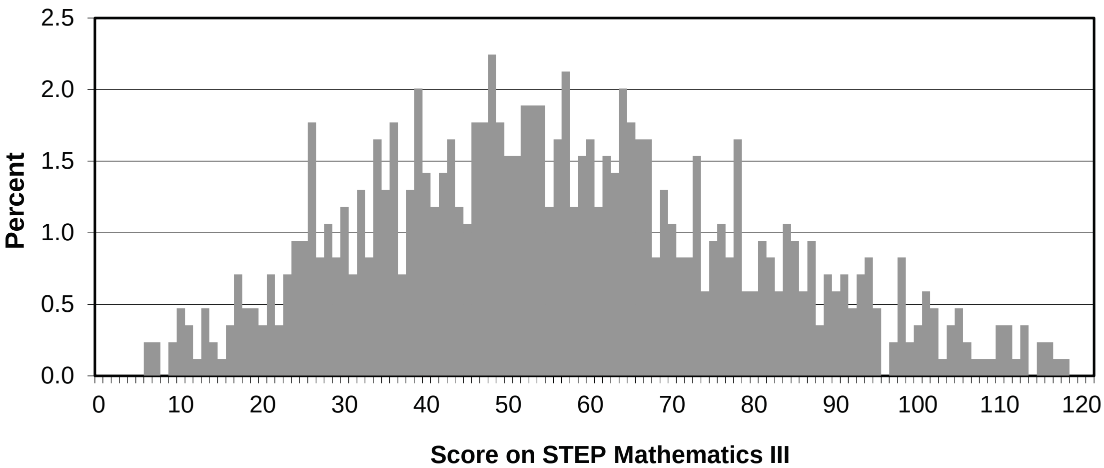
Grade boundaries

Maximum Mark	S	1	2	3	U
120	88	64	55	32	0

Cumulative percentage achieving each grade

Maximum Mark	S	1	2	3	U
120	11.0	36.6	50.1	85.1	100.0

Distribution of scores



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Language Assessment
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