# M1.4 – Understand simple probability

## Tutorials

Learners may be tested on their ability to:

* Use the terms *probability* and *chance* appropriately
* Understand the probability associated with genetic inheritance.

## Probability and chance

**Probability**

When I toss a coin there are two possible outcomes, it can land facing heads up, or tails up. There are only two possible outcomes, but with each toss of the coin it is impossible to predict which of these two things will occur. Therefore, we can say that the outcome from the toss of a coin is random. Although the outcome of each individual coin toss is random, we know that (if the coin is unbiased) heads and tails are equally likely therefore we can say that there is a 50% probability of getting heads and a 50% probability of getting tails. This becomes extremely useful when the coin is tossed repeatedly. We can reason ‘forwards and backwards’ using the concept of probability to make meaningful statements about the results:

In the ‘forwards’ direction we can make useful predictions about the overall outcome of many repeats, even though each repeat is itself random. So, for example if we know that the coin will be tossed 100 times we can predict that there will be approximately 50 heads and 50 tails.

In the ‘backwards’ direction we can use the outcome of many repeats to assess whether our understanding of the system is correct. If the actual outcome of 100 tosses of the coin is 48 heads and 52 tails we would not be surprised – this is approximately the ratio of heads to tails we expected based on our assumption that the coin is unbiased. If, however we get 99 heads and only 1 tail we would be surprised and might suspect that the coin is biased. To put exact numbers on how surprised we are, or more precisely how confident we are that our assumption about the system was wrong, we use statistical tests (see M1.9).

The probability of an event occurring is the likelihood of it occurring. The probability of an event A, written P(A), can be between zero and one, with P(A) = 1 indicating that the event will certainly happen and with P(A) = 0 indicating that event A will certainly not happen. When I estimate the probability of a coin toss landing on heads, it would be 0.5. If there is more than one variable involved, then you calculate the probability that an individual has one variable outcome AND the other variable outcome by multiplying the separate probabilities together. For instance if I wanted to calculate the probability of getting heads on TWO coin tosses that would be 0.5 x 0.5 = 0.25.

**The difference between probability and chance**

In statistics we use **probability** as the appropriate term for expressing likelihoods (as ratios, decimals or percentages)

For example – When tossing a coin we have a **probability of 0.5** of the coin landing on heads – with this information we can predict that with ten coin flips, approximately five of them will land heads up.

In everyday speech ‘**chance’** is often used to mean the same thing as ‘**probability’**. For example we might say ‘I think the **chance** of rain today is about 50/50’ meaning that we think there is a 50% **probability** of rain. However, when we use the word ‘chance’ in commenting on statistics we are using it to talk about the random deviations from probability that can occur (and especially whether we think these random deviations are sufficient to explain why the outcome did not exactly match our expectation based on probability).

Using coin tosses as an example once more, if we actually got six heads from ten tosses of the coin we might say ‘getting six rather than the predicted five was due to **chance’**. If we got nine heads we might say ‘this is too far from the predicted outcome to be explained by **chance** and so we now believe this coin is biased’. The cut-off point for how far away from the prediction (based on probability) the results have to be before they cannot be explained by chance is where statistical tests come in (see M1.9).

The effect of chance, in percentage terms, is largest when the number of repeats is small. Clearly if we only toss a coin four times, a single result has a big effect on the percentage of heads whereas if we do 1000 repeats the effect of a single result is much smaller. This is the reason that experiments often use many repeats, or take many samples.

**Probability and patterns of genetic inheritance**

|  |  |
| --- | --- |
| **Parents** | **Vg / vg x Vg / vg** |
| **Allele inheritance patterns for offspring (four equally likely outcomes):** | **Vg / Vg** | **Vg / vg** | **vg / Vg** | **vg / vg** |
| **Offspring Genotypes****(three outcomes):** | **Vg / Vg** | **Vg / vg** | **vg / vg** |
| **Offspring Phenotypes****(two outcomes):** | **Normal wings** | **Tiny wings** |

In a genetic cross of two *Drosophila melanogaster* (fruit flies) that are each heterozygous for the mutant allele of the *vestigial* gene(which is recessive and found on chromosome 2), we predict that the probability of each individual offspring being a recessive homozygote (which means it will have tiny wings) is 0.25, the equivalent of saying that 1 in 4 offspring will have tiny wings.

This can be displayed as a Punnett square showing the four equally likely offspring:

|  |  |  |
| --- | --- | --- |
|  |  | Vg / vg female parent gametes |
|  |  | Vg | vg |
| Vg / vg male parent gametes | Vg | **Vg / Vg****Normal wings** | **Vg / vg****Normal wings** |
| vg | **Vg / vg****Normal wings** | **vg / vg****tiny wings** |

Things get a little more complicated when we include a second genetic trait. Individuals that are homozygous for the recessive mutant version of the *ebony* gene (found on chromosome 3), have very darkly coloured bodies (Heterozygotes sometimes have slightly darker bodies). If the parents are heterozygous at both the *ebony* locus and the *vestigial* locus, then the probability of an individual having tiny wings and dark bodies is 0.25 x 0.25 = 0.0625 or 1/16.

Again this can be shown in a Punnett square giving the 16 equally likely outcomes:

|  |  |  |
| --- | --- | --- |
|  |  | Vg / vg Eb / eb female parent gametes |
|  |  | Vg Eb | vg Eb | Vg eb | vg eb |
| Vg/vg Eb/eb male parent gametes | Vg Eb | Vg/Vg Eb/EbNormal wingNormal body | Vg/vg Eb/EbNormal wingNormal body | Vg/Vg Eb/ebNormal wingNormal body | Vg/vg Eb/ebNormal wingNormal body |
| vg Eb | vg/Vg Eb/EbNormal wingNormal body | vg/vg Eb/Ebtiny wingNormal body | vg/Vg Eb/ebNormal wingNormal body | vg/vg Eb/ebtiny wingNormal body |
| Vg eb | Vg/Vg eb/EbNormal wingNormal body | Vg/vg eb/EbNormal wingNormal body | Vg/Vg eb/ebNormal wingebony body | Vg/vg eb/ebNormal wingebony body |
| vg eb | vg/Vg eb/EbNormal wingNormal body | vg/vg eb/Ebtiny wingNormal body | vg/Vg eb/ebNormal wingebony body | vg/vg eb/ebtiny wingebony body |

And the numbers of each of those outcomes giving each of the four possible phenotypes is easier to see if we colour code:

|  |  |  |
| --- | --- | --- |
|  |  | Vg / vg Eb / eb female parent gametes |
|  |  | Vg Eb | vg Eb | Vg eb | vg eb |
| Vg/vg Eb/eb male parent gametes | Vg Eb | Vg/Vg Eb/EbNormal wingNormal body | Vg/vg Eb/EbNormal wingNormal body | Vg/Vg Eb/ebNormal wingNormal body | Vg/vg Eb/ebNormal wingNormal body |
| vg Eb | vg/Vg Eb/EbNormal wingNormal body | vg/vg Eb/Ebtiny wingNormal body | vg/Vg Eb/ebNormal wingNormal body | vg/vg Eb/ebtiny wingNormal body |
| Vg eb | Vg/Vg eb/EbNormal wingNormal body | Vg/vg eb/EbNormal wingNormal body | Vg/Vg eb/ebNormal wingebony body | Vg/vg eb/ebNormal wingebony body |
| vg eb | vg/Vg eb/EbNormal wingNormal body | vg/vg eb/Ebtiny wingNormal body | vg/Vg eb/ebNormal wingebony body | vg/vg eb/ebtiny wingebony body |

So from our probability calculation, illustrated with the Punnett square we can say, for each offspring there is a 1/16 or 0.0625 or 6.25% probability that it will be doubly homozygous for the recessive alleles and therefore display the double mutant phenotype of tiny wings and an ebony-coloured body.

Similarly there is a 3/16 probability of each individual having normal wings but an ebony-coloured body. And 3/16 probability of each individual having tiny wings but a normal-coloured body. There is a 9/16 probability of each offspring appearing normal (although of course many of these flies will be heterozygotes, carrying mutant alleles at one or both loci).

This leads to the classic expected ratio of phenotypes in the offspring in this kind of breeding experiment:

9 : 3 : 3 : 1

What if the results you get from such an experiment don’t exactly match the ratio you’d expect based on your probability calculations?

It could just be due to chance or it could indicate that your assumptions were wrong. Statistical tests (in this case the chi-squared test) (see M1.9) will help you decide if the deviation away from your expectation is big enough to demand a re-think of your assumptions. If so, maybe the loci are linked (on the same chromosome) so they won’t be inherited truly independently. Or maybe something else weird is happening (e.g. the double mutant offspring are not surviving to adulthood to be counted).

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