Precision vs. Accuracy – why is there so much confusion?

[An email from a customer] I noticed my sons were struggling with defining accuracy and precision well. So I went and looked up the terms and examples which would make it easier. It appears that most of high school physics across the country and even colleges use a different definition for precision than you do. It appears that you use the same definition that my husband uses, which would be precision is more about significant digits versus achieving the same result over and over again . All these websites like to use target pictures as examples. Do you all have any comment on that?

[Our response to this customer]

"I did not use the arrow analogy because although it is a correct analogy, it is very misleading because it is always poorly explained. I have never seen it correctly explained in any text. Writers use it because everyone else uses it, and its explanation *seems* clear and obvious, even though it is not. Shooting arrows implies a human action of delivering something (arrows) to something else (target). But in the context of science, the concepts of accuracy and precision refer to the *taking* of measurements. It is not we who give to something else; it is the something else that gives something to us, namely, its measurements. Thus, students have a clear idea of how precision applies to shooting arrows, but they do not have a clear idea of how the arrow analogy applies to the taking of measurements. I have always thought the arrow analogy to be particularly terrible just because it is so misleading in this respect, and everyone keeps using it without noticing the pedagogical failure involved.

Now, as the text explains, precision in measurements has to do with the resolution in the measurement, the fine-ness or graininess of the measurement. If I take measurements with a more precise tool, my measurement will consistently "hit" more closely together. And if the measurements are also accurate, then the tightly clustered measurements will be close to the true measurement. This is where the arrow analogy comes in.

Here is another example. Let's say we have a box whose true length is 9.85000 inches. As described in the text, when measuring we know all digits with certainty except the last one, which is an estimate between the two finest marks on the scale. If we measure the box's length with one of those rulers for children marked off to the nearest ¼ inch, the length falls between 9 ¾ inches and 10 inches on the ruler. People will estimate differently, but the estimates might be values such as 9.8 or 9.9 inches (all valid measurements). If, instead of the low-precision ruler, we use a higher-precision ruler marked off in tenths of an inch, we still must estimate, but now we are estimating the hundredths value instead of the tenths value. The length falls between 9.8 and 9.9 inches, so our estimates will be values such as 9.83, 9.84, 9.85, 9.86, or

9.87 (all valid measurements). We can get even more precise by using some kind of instrument that can measure to the nearest hundredth of an inch. Now our measurements will be values such as 9.849, 9.850, or 9.851. These are all very close together—the spread between the highest and lowest estimates is only 0.002 inches.

So you see that precision is all about the fine-ness or resolution of the measurement, and this is signified by the number of digits we have in the measurement, the significant digits. But greater precision in the measurement allows us to make repeated measurements that are close together, just as 9.849, 9.850, and 9.851 are all much closer together than 9.7, 9.8 and 9.9 are. This is analogous to the arrows being close together on the target.

The arrow analogy always shows arrows close together to signify precision, and arrows clustered at the center to signify accuracy. In the measurement example above, a device that measures to the nearest hundredth of an inch could be poorly manufactured so that all the measurements are off by a tenth of an inch. This would result in measurements of 9.749, 9.750, or 9.751. These are all close together (like the arrows), but they are inaccurate because they are not close to the true value. The target analogy illustrates this with arrows clustered closely together but not at the bull's eye.

Finally, I have found that students often fail to learn the accuracy/precision definitions at first until they find out from the quiz that they are expected to learn the definitions in the text thoroughly and be able to quote them (rather than giving vague or superficial answers lacking in detail). The objectives say this, but kids being what they are, they often under-estimate how thorough they need to be. They need to be given a poor score on the question when this happens and told to sharpen up their ability to give a thorough and correct answer to the question next time around. The answers in the sample answers are the answers I expect my students to deliver, and they do. Students will meet our high expectations when we hold them accountable for doing so, and the result is high-quality learning. When they must answer the question over and over on quizzes over a period of months, then mastery and long-term retention are achieved. These are the goals of our methodology."