0.1 The Idea Behind the IA

0.1.1 What is an IA?

Before planning out an IA or even trying to choose a topic, it is important to understand what an IA is; its nature and purpose.

The IA is designed to be a scientific exploration aimed at answering a question of the student's choice. It is supposed to be a resemblance of a real academic paper, giving the student insight on the structure and procedures of a real scientific investigation. This should be reflected not only in the tone of the report, but the structure of the entire investigation.

0.1.2 Scientific Theories

To understand how a scientific theory is developed, it is important to know what it is and why we need them.

On a basic level, a scientific theory is a set of "rules"/relationships that describe some process.

This creation of a theory is made up of 3 simple steps.

1. A set of initial premises is established.
   - These are essentially assumptions/guesses that are made in order to develop an argument from them. They are some basic, fundamental truths about the process in question.
2. The consequences of these premises are calculated.
   - If these assumptions are true, what else would be true about the process we are investigating?
   - These consequences are whenever possible expressed mathematically (writing equations to indicate relationships between different quantities)
3. These consequences are verified (compared) with experiment.
   - If they match, then your theory can be used to describe this process
   - If your consequences do not match with experiment then the theory is wrong. Either the assumptions are wrong and do not represent the system in the experiment, or the consequences were calculated incorrectly.

It is important to note that theories do not actually represent what is happening in "reality". They are meant to provide an accurate prediction of how a process will occur based some physical justification. That doesn't imply that they are "true". This can manifest itself in two keys ways:

At times, making "incorrect" assumptions, significantly simplifies the calculation of the consequences of these assumptions, while still yielding accurate results. For example physicists often assume friction to be negligible. While this is clearly not representative of a real life system, this can still provide predictions to a certain degree of accuracy, making the theory completely valid (until higher accuracy is required).

Some theories are “incorrect” due to a lack of data/evidence that would contradict some of the calculated consequences. A great example of this is the evolution of the atomic model. Each of the atomic theories explained what was know about the atom at the time of their creation. Even to this day some of them can still be used to make predictions (E.G. Bohr-Rutherford model is still useful for counting valence electrons in chemistry, even though Shrödinger’s model is now considered to be more complete.).

For this reason, it is impossible to prove a theory to be “true”, as there is always the possibility of there being some unknown information that is not being taken into account (E.G. a lack of sufficiently precise measurements). It is only possible to prove a theory to be wrong, you just have to find an instance when it does not match with experiment.

Click ***here*** to view Feynman’s video on the Scientific Method.

In the context of an IA, it is unlikely that you will be able to come up with a completely unique theory, built from the most basic premises ground up, however this approach is very useful when developing your question and hypothesis.

Further sections, will look at “theory creation” in the context of a Science IA.

0.1.3 Making Assumptions/Guessing the Answer

When attempting to create an entirely original theory, this is arguably the most difficult step. The approach to this is entirely situational and there are no “predefined” rules on how to make a good guess.

You can try to look at all of the constituent elements of the process you are examining individually, and write down everything that you are confident is true about it. This can be looking at the environment/surroundings of the phenomenon, the objects involved in the interaction and the process itself.

In most cases however, you will not need to come up with assumptions of your own, as someone has probably created a complex theory describing your process before (E.G. Newton’s Laws of Motion). In this case you will simply have to apply this theory. You don’t even need to write down its basic assumptions, but can rather state the formulas relevant to the special case you are investigating (use the theories’ consequences as YOUR premises). Make sure to cite these properly.

0.1.4 Calculating the Consequences

This will effectively be your hypothesis. You are coming up with expectations/predictions for the process you are investigating.

This is once again a very situation dependent task with no “pre-defined” instructions. This sometimes requires quite a bit of in-dept study of your topic. It is however important to understand what your final hypothesis/consequences should look like.

I personally split a theory's consequences (hypotheses) into 3 main types.

0.1.4.1 A Qualitative Consequence

This is a statement of an expected general trend.

E.G. I expect the liquid to change color from yellow to blue, or as x increases y should also increase.

This type of prediction is highly likely to be correct (due to its vagueness), very easy to observe and formulate. In most cases however, this type of consequence is simply not useful in any real life applications or for future development of the theory. Try and stay away from using a "qualitative" consequence as your hypothesis.

In some cases (especially biology), this can be the only type of prediction you can possibly make. In these cases its use is perfectly acceptable. You will however have to put in more effort when analyzing data. (More on that later)

0.1.4.2 A "Type of Relationship" Consequence

This is a statement on the kind of trend you expect

E.G. y will increase proportionally to x. or as x increases, y will increase exponentially.

This type of trend is also quite likely to be correct, however it is not as vague as the Qualitative Consequence. If you know what kind of relationship to expect, you can always use software to draw a line of best fit and have an exact formula you can use to model this process. This is useful information, as you can now predict your process quantitatively.

0.1.4.3 The Exact Relationship Consequence

This is a statement of the exact relationship between your dependent and independent variable. It is completely dependent on measured values and known fundamental constants.

E.G. I predict the area of a circle will be $A = \pi r^2$, where $\pi = 3.14$.

If I know r, I can directly predict the area. I do not need to calculate some other coefficients from this experiment. My prediction can be made purely with pen and paper.

This is the best kind of possible hypothesis you can make. It is very useful as you with it, you can make predictions for a process without ever having to make it actually happen!

0.1.5 Comparing to Experiment & Analysis

Each of the types of consequences/hypotheses above, has its own approach towards analysis (These are not always limited to my suggestions).

0.1.5.1 Evaluating a Qualitative Consequence

While this may sounds like an “easy” hypothesis to analyze (just see if the color changed), this is often not the case. With a qualitative consequence, the purpose of your investigation is learning something new about the process through the experiment you did not know before.

In order to maximize what you can get out of your experiment, you must find a way to quantify the dependent variable as best as possible, ideally to the point where you can draw some graph. E.G. Instead of just saying, as x increased y increased, as x increased by this much, y increased by this much.

With this new detailed data you can construct a new line/curve of best fit that can be used to model the process. Ideally, you would have multiple samples with a line of best fit for each of the data sets, so that you can compare them and see if there are any similarities. You should try your best to explain why the fit/equation is the way it is (explain why it is proportional, or why it is exponential. Ideally trying to come up with some initial assumptions).

0.1.5.2 Evaluating a “Type of Relationship” Consequence

Just like in the previous case you want to have some kind of line/curve of best fit for your data. Of course, you must check that predicted type of relationship was actually the “best fit”. It is still preferable to design an experiment where you can construct and compare multiple graphs and check your theory for consistency.

It may be possible to make some physical justification for the coefficients of your best fits (E.G. Explain order of magnitude of a coefficient), however this can be difficult.

0.1.5.3 Evaluating an Exact Relationship Consequence

This can be done in multiple ways. The simplest is once again drawing a line of best fit. You would then compare your experimental coefficients with your expected coefficients in your equation (this will not automatically take into account experimental uncertainty and may be problematic).

It may also be visually useful to draw your “actual” points along side your predicted graph.

For IB physics, a required method of verification is “linearization”. It is applicable in many cases and can significantly simplify your analysis

0.1.5.4 Linearization

The idea behind the process of linearization is drawing a linear graph of a non-linear equation.

In order to be able to accomplish this, you must have some kind of equation to work with. You will then select an x and y axes of your graph, so that it makes a straight line. In other words, linearize it in the form

$$y = kx + b \tag{1}$$

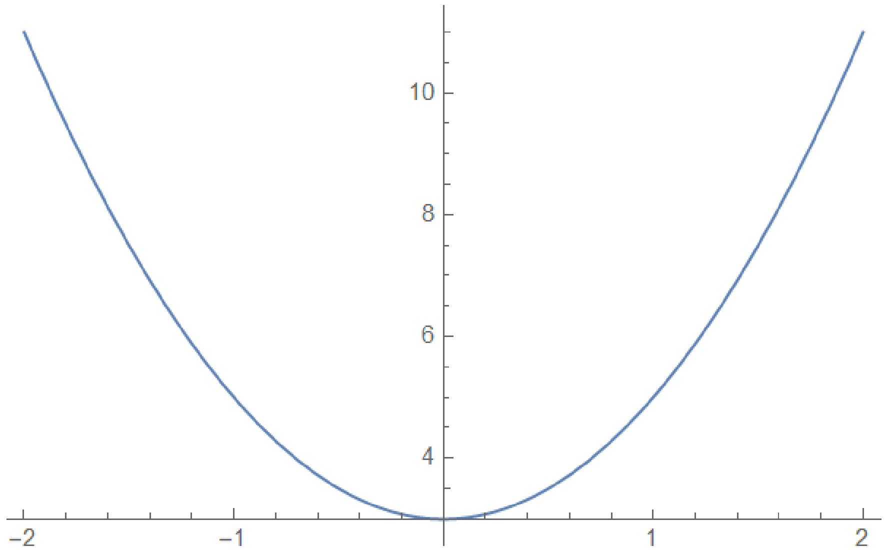

Figure 1: A graph of $z = 2n^2 + 3$

Let's look at an example.

Suppose your expected relationship was:

$$z = 2n^2 + 3$$

This is obviously is in now way a linear relationship and will look something like this.

Here we look for similarities between equation (1) and the equation above. We can select the following linearization:

$x = n^2$

$y = z$

Now if we calculate our new data set of y and x and plot them, this should yield a straight line that will follow the following equation:

$$y = 2x + 3$$

Where:
$k = 2$
$b = 3$

Now we just need to draw a line of best fit to verify if $k = 2$ and $b = 3$.

Hopefully your new graph will look something like this:

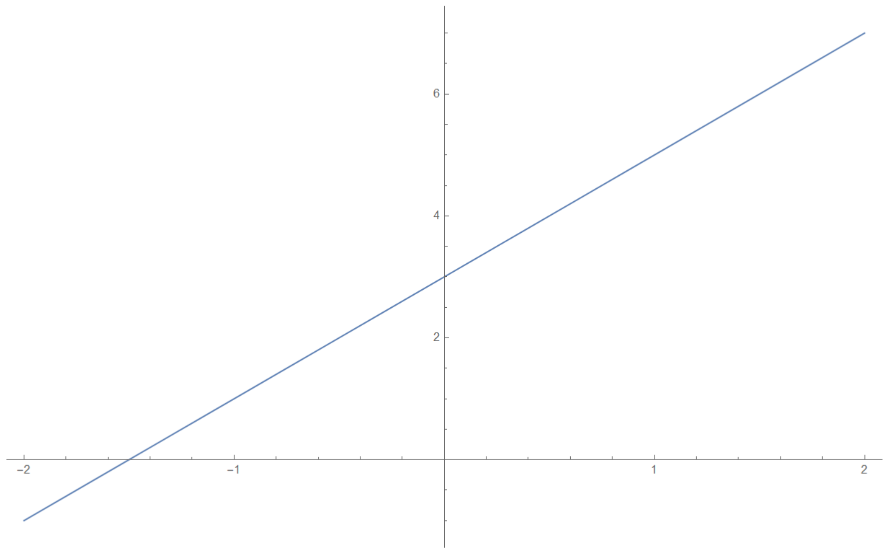

Figure 2: A graph of $y = 2x + 3$

To wrap up, ***here*** is another excerpt from a Feynman lecture on theories.

0.1.5.5 Independent Measurements

There is however one universal rule that applies to everything.

Consider a case where you have a relationship between two variables. x - independent, y - dependent.

It is defined by some function:

$$y = f(x)$$

To correctly evaluate this relationship, in your experiment you must make independent measurements for both the x and the y value. You cannot calculate your y value using your x value and your hypothesis as that would always give you 100 % correlation with the hypothesis!