PHYS379 Theoretical Physics Research Guide

This is a list of guidelines on how to do research in PHYS379 Theoretical Physics Group Project. Research is hard, and it is not really possible to produce a prescriptive "how to" list (or everyone would be able to do research, which they cannot). Any such list will be highly subjective; this list contains some of my views and it is born out of my experience in doing my own research and in supervising PHYS379 for many years.

1) Be honest. Although this is a list of guidelines, number 1) is a rule, not a guideline. Don't cheat. Don't cut corners when doing calculations. Give due credit to others (e.g. colleagues and previous authors). A reputation for honesty is the most important thing for an academic.
2) As a theoretical physicist, you have to be able to calculate something. Read previous works (e.g. PHYS379 notes, textbooks, research papers) to learn how to calculate something related to your chosen topic. Even if someone else in your group is tasked with doing the bulk of coding, say, I strongly advise you to do some preliminary calculations of your own so you can understand what is going on (on to the next point…).
3) As a theoretical physicist, you should also attempt to understand (everything). Do not build a black box consisting of a complicated model or some proprietary code such that it is impossible to tell what it does (even if it gives the "correct" answer). Imagine you want to write a code to calculate and understand the behaviour of observable G as a function of parameters a, b, c, d. Do not begin by writing the whole code, hoping it works, and, then, trying to understand what is happening in some complicated four-dimensional parameter space. Instead, do the following:
   I. Set $b = c = d$. Write a code to determine $G(a)$. Produce data for various a values. Plot $G(a)$. Try to deduce the dependence $G(a)$. Perhaps try a log-log plot. Is it possible to do some "benchmarking": compare your calculation with previous works (to check what you've done is correct)? Great, job done? No, at this point, you are half done with $G(a)$. Now you need to understand. Is it possible to produce some analytics for $G(a)$? Possibly very hard…but perhaps in limits e.g. $a \to 0$ or $a \to \infty$? If not complete analytics, can you understand qualitatively?
   II. Set $a = c = d$. Repeat for $G(b)$.
   III. Repeat for $G(c)$ and $G(d)$.
   IV. Then try to repeat with non-zero parameters a and b. OK, there's a huge four-dimensional parameter space, so this could take a very long time. However, if you understand something, it is likely you can deduce where, in this four-dimensional parameter space, there is some interesting physics.
   V. You probably won't be able to complete all of this. But, that's OK, if you understand something about $G(a)$ which you didn't at the start.
4) As you may have deduced by now, a theoretical physics project mainly consists of calculating and understanding (there are other minor elements, too). They almost always come in the order of calculating first followed by understanding, unless you

are a genius or doing something trivial (the first is unlikely, the second is not recommended).

5) An important “minor” element is reading research articles. You do this for learning methodology, understanding and determining what is already known; it is recommended to reproduce previous work as part of the development of your own model, but be sure, in the report, to clearly state what is previous work and what is your own original work. Warning: there is a potential rabbit hole of reading too much and being confused by too much conceptually new material. Some confusion and lack of understanding is normal at the beginning of a project (and this is good, otherwise your project is probably trivial). There comes a stage, however, when the route to enlightenment is not to read yet more, but to calculate. There are two main elements: calculate and (then) understand.
6) Research is hard and the outcomes are not guaranteed. This is not a lecture module where the syllabus is well defined. It is possible for a sub-project to “fail” e.g. your code isn’t complete in the time given or it doesn’t give the outputs you expect. The supervisor will give broad advice, but is unlikely to help to the extent of debugging or writing your code because (i) by week 6, you probably know more about the project than the supervisor and (more importantly) (ii) research is hard and the outcomes are not guaranteed; there is a degree of jeopardy.
7) However, you need to write a group report in PHYS379 and, presumably, you want to get decent marks? While it is OK to write about a sub-project that “fails” (because you can document the process, rationale, and possible reasons for failure), your group should also minimise risk. One obvious way is to run more than one sub-project, possibly on quite different sub-topics, and possibly with each sub-project having a different level of risk (e.g. a group might run a sub-project which is fairly straightforward “safe” and another sub-project which is ambitious and risky). Another way to minimise risk can be for different people to do the same calculation independently (although this costs resources, see 8). The main aim of the supervisor is to ensure that the group as a whole succeeds in producing enough original research across their sub-projects to write a report (no report has ever failed PHYS379).
8) As a group, use your resources wisely. Your main resource is your time. Don’t rely on one person to do all the coding --- this can create a bottleneck and it doesn’t minimise risk. At some stage, you might find that an activity is not going well and you might wonder whether to continue with it. Beware of the gold-miner’s paradox (aka sunk-cost fallacy): think in terms of the future resources (your time) that you need to spend to complete the activity, forget about the resources (your time) that you have already spent/wasted on it. i.e. “don’t throw good money after bad”.