Carl Wieman guide to grad student project

A. Importance and fit and delineate goals

1) What is **important in field**?
What are important questions or problems? Where is the field heading? Are there advances in the field that open new possibilities?

2) Opportunity **fits solver's expertise?**
If and where are there gaps/opportunities to solve in field? Given experts' unique perspectives and capabilities, are there opportunities particularly accessible to them? (could involve challenging the status quo, questioning assumptions in the field)

3) **Goals, criteria, constraints?**
What are the goals for this problem? Possible considerations include:

a. What are the goals, design criteria, or requirements of the problem or its solution?
b. What is the scope of the problem?
c. What constraints are there on the solution?
d. What will be the criteria on which the solution is evaluated?

B. Frame problem.

These decisions lead to a more concrete formulation of the solution process and potential solutions.

4) What are **important underlying features or concepts** that apply, and which available information is relevant to solving?
(When appropriate) Create/find a suitable abstract representation of core ideas and information
Examples: physics – equation representing process involved, chemistry – bond diagrams/potential energy surfaces

5) Which potential **predictive frameworks/models to use?** (decide among possible predictive frameworks or create framework) This includes deciding on the appropriate level of mechanism and structure that the framework needs to embody to be most useful for the problem at hand.

6) How to **narrow down the problem?** Involves formulating **specific questions and hypotheses.**

7) **Related problems?**
What are related problems or work seen before, and what aspects of their solutions might be useful in the present context? (may involve reviewing literature and/or reflecting on experience)

8) What are **potential solutions?**
Based on experience and fitting some criteria for solution they have for a problem having general features identified.

9) Is problem **plausibly solvable?** And is it worth pursuing given the difficulties, constraints, and uncertainties?

C. Plan process for solving.

These decisions establish the specifics needed to solve the problem.

10) What **approximations or simplifications to make?** How to simplify the problem to make it easier to solve? How to justify?

11) How to **decompose** the problem into more tractable sub-problems? (Independently solvable pieces with own sub-goals.)

12) Which are **areas of most difficulty or uncertainty** in plan of solving?
Including, what are acceptable levels of uncertainty with which to proceed at various stages?

13) What **information is needed** to solve the problem?
What will be sufficient to test and distinguish between potential solutions?

14) **Priorities.** What to prioritize among competing considerations? What to do first and how to obtain needed resources?
Considerations could include: What's most important? Most difficult? Addressing uncertainties? Easiest? Constraints (time, materials, etc.)? Cost? Optimization and trade-offs? Availability of resources? (facilities/materials, funding sources, personnel)

15) Specific **plan** for getting information?
a. What are the general requirements and what approach to pursue? (often decided early in process as part of framing)
b. How to obtain needed information? (This could involve many discipline and problem-specific investigation possibilities such as: designing and conducting experiments, making observations, talking to experts, consulting the literature, doing calculations, building models, or using simulations.)
c. What are **achievable milestones,** and what are metrics for evaluating progress?
d. What **possible alternative outcomes** and paths may arise during p. s. process, and what would be paths to follow for the different outcomes?

D. Interpret information and choose solution(s).

Includes deciding how to analyze, organize, and draw conclusions from the information in hand.

16) **Calculations and data analysis**. Decide what calculations and data analysis are needed? Then decide to carry those out.

17) **Represent and organize information**. Best way to represent and organize available information to provide clarity and insights? (usually specialized & technical representations related to key features)

18) **How believable is information?** Is information valid, reliable, and believable (includes recognizing potential biases)?

19) **Compare to predictions.** As new information comes in, particularly from experiments or calculations, how does it compare with expected results (of predictive framework)?

20) Any **significant anomalies?** If a result is different than expected, how should you follow up? Could involve deciding:
a. Does potential anomaly fit within acceptable range of predictive framework(s) (given limitations of framework and assumptions)?
b. Is potential anomaly an unusual statistical variation, or relevant data? Is it within uncertainty?

21) What are **appropriate conclusions** based on the data? (involves making conclusions and deciding if they're justified)

22) What is the **best solution?** Involves evaluating and refining candidate solutions throughout problem-solving process. Not always narrowed down to a single solution. May include deciding:
    a. Which of multiple candidate solutions are consistent with all available information and which can be rejected? b. What refinements need to be made to candidate solutions?

E. Reflect.

Reflection decisions occur throughout the process and include deciding whether assumptions are justified, whether additional information is needed, how well the solution approach is working, and if potential and final solutions are adequate.

23) **Assumptions + simplifications appropriate?**
Are previous decisions about simplifications and predictive frameworks still appropriate?
    a. Do the assumptions and simplifications made look appropriate considering new information? (reflect on assumptions)
    b. Does predictive framework need to be modified? (Reflect on predictive framework.)

24) Is **additional knowledge/information needed?** (Based on ongoing review of one's state of knowledge.) Could involve:
    a. Is solver's relevant knowledge sufficient?
    b. Is more information needed and if so, what?
    c. Does some information need to be checked? (e.g. need to repeat experiment or check a different source?)

25) How well is the **problem-solving approach working?** Does it need to be modified, including do the goals need to be modified? (Reflect on strategy by evaluating progress toward solution)

26) Is the **chosen solution adequate?** (Reflect on solution) Includes ongoing reflection on potential solutions, as well as final reflection after selecting preferred solution. Can include:
    a. Decide by exploring **possible failure modes and limitations** – "try to break" solution.
    b. Does it "make sense" and pass discipline-specific tests for solutions of this type of problem?
    c. Does it completely **meet the goals/criteria?**

F. Implications and communication

Decisions about the broader implications of the work, and how to communicate results effectively.

27) **Broader implications?** What are the broader implications of the results, including over what range of contexts does the solution apply? What outstanding problems in field might it solve? What novel predictions can it enable? How and why might this be seen as interesting to a broader community?

28) Audience. What is the **audience for communication** of work, and what are their important characteristics?

29) Presentation. What is the **best way to present the work** to have it understood, and its correctness and importance be appreciated? How to make a compelling story of the work?

Problem-solving decisions (occurrence in expert interviews)

Selection and goals	Frame problem	Plan process for solving	Interpret info and choose solutions	Reflect	Implications and communicate results
1.[c] (61%) What is important in field?	4. (100%) Important features and info?	10. (100%) Approximations and simplifications to make?	16. (81%) Which calculations and data analysis?	23. (77%) Assumptions and simplifications appropriate?	27. (65%) Broader implications?
2. (77%) Opportunity fits solver's expertise?	5. (100%) What predictive framework?	11. (68%) How to decompose into sub-problems?	17. (68%) How to represent and organize information?	24. (84%) Additional knowledge needed?	28. (55%) Audience for communication?
3. (100%) Goals, criteria, constraints?	6. (97%) How to narrow down problem?	12. (90%) Most difficult or uncertain areas?	18. (77%) How believable is information?	25. (94%) How well is solving approach working?	29. (68%) Best way to present work?
	7. (97%) Related problems?	13. (100%) What info needed?	19. (100%) How does info compare to predictions?	26. (100%) How good is solution?	
	8. (100%) Potential Solutions?	14. (87%) Priorities?	20. (71%) Any significant anomalies?		
	9. (74%) Is problem solvable?	15. (100%) Specific plan for getting information?	21. (97%) Appropriate conclusions?		
			22. (97%) What is best solution?		

From Price et al (2021) A Detailed Characterization of the Expert Problem-Solving Process in Science and Engineering: Guidance for Teaching and Assessment https://www.lifescied.org/doi/full/10.1187/cbe.20-12-0276