Bridging Observation and Modeling: Classroom Design Using Snow Crystal Growth Experiments and Excel-Based Simulations

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Extended Abstract

In meteorological research, field observations, laboratory experiments, and numerical simulations are complementary approaches to understanding natural phenomena. Each approach provides a different representation of nature, with different strengths and limitations. Understanding not only the scientific results obtained from these approaches but also what each representation includes, simplifies, or omits is an important component of meteorological education.

This study presents a classroom design using snow crystal growth as a common theme to connect observation, laboratory experimentation, numerical modeling, and model literacy. Snow crystals provide a particularly suitable context because they combine visual beauty with fundamental physical processes, including water-vapor diffusion, phase change, and anisotropic crystal growth. Their complex morphology also naturally raises questions about how relatively simple physical processes and local growth rules can produce complex structures.

From observation to laboratory experiment

The activity begins with observation. Snow crystals have attracted scientific interest for centuries, and their forms naturally lead to questions about how and why they grow. However, natural snow crystals cannot always be observed in the classroom because their occurrence depends on geographical location, season, and weather conditions. Laboratory experiments therefore provide an alternative way to investigate their growth under partially controlled conditions.

Simple diffusion chambers can be constructed using dry ice or other cooling methods. In these experiments, students do not simply produce and observe snow crystals. They also measure the temperature at the location where the crystals grow and relate the observed growth to the temperature distribution within the chamber. In particular, vigorous dendritic growth is commonly observed near −15°C. The difference in saturation vapor pressure between water and ice is greatest around this temperature, providing favorable conditions for ice-crystal growth. Thus, a visually attractive observation becomes the starting point for asking a physical question: Why does the crystal grow there?

At the same time, the laboratory experiment itself has limitations. Growth requires time, experimental conditions are only partly controllable, and repeated experiments do not necessarily produce identical crystals. More fundamentally, a crystal grown on a supporting material in a diffusion chamber is not identical to a freely growing natural snow crystal. The laboratory system should therefore be regarded as a physical model of nature, rather than as nature itself.

This distinction is pedagogically important. The sequence can be expressed as:

Nature → Physical Model → Numerical Model → Model Literacy

Observation tells us what happens. Laboratory experiments allow us to investigate why under controlled conditions. Numerical models allow us to test which processes and assumptions may be important. Finally, comparison among these different representations encourages students to consider what a model can—and cannot—explain. This framework became the central organizing principle of the lesson.

Extending the laboratory experiment through modeling

Simple diffusion-chamber experiments are engaging and are useful for demonstrations and public outreach. However, for a university-level laboratory activity, their educational value can be limited relative to the time required for crystal growth. Students are nevertheless strongly interested in snow crystals. The laboratory activity was therefore combined with simple computer simulations so that the experiment could be developed into a broader learning activity about both snow crystal growth and modeling itself.

The computational component uses Microsoft Excel and VBA. Excel was selected because it provides a familiar environment in which students can visualize the model directly on a grid, change parameters, run simulations, and compare results without requiring a specialized programming environment.

Rather than introducing a single relatively complex model, three progressively different representations of snow crystal growth are used:

1. Diffusion-Limited Aggregation (DLA) Model— a particle-based model;
2. Cellular Automaton (CA) Model— a cell-based model with hexagonal symmetry; and
3. Diffusion-Field Model — a field-based model that explicitly represents water-vapor supply.

These can be summarized conceptually as particle → cell → field. The purpose of the sequence is not simply to generate increasingly realistic snow crystal images. Instead, each model introduces a different representation and allows students to ask what must be added to explain a particular feature of snow crystal growth.

Three progressively richer models

In the first model, DLA, virtual particles perform random walks and attach to a growing cluster. The model readily generates branching and emergent structures, demonstrating how complex patterns can arise from simple local rules. However, it contains no built-in six-fold symmetry, and repeated runs produce different structures. The limitation of the model therefore becomes immediately visible: although branching occurs, the result does not necessarily resemble a snow crystal.

The second model introduces a cellular automaton with six-fold neighborhood symmetry. Both deterministic and stochastic versions can be explored. Adding hexagonal symmetry produces patterns that appear more snow-crystal-like, but this immediately raises another question: Can the model also represent the supply of water vapor?

The third model therefore introduces a discretized vapor field. Water vapor diffuses across the grid and is consumed near the ice interface. Local growth rules also represent anisotropy and enhanced growth near crystal tips. This produces dendritic structures that visually resemble snow crystals more closely. However, the model remains intentionally simple. It is neither a phase-field model nor a molecular-dynamics model, and it should not be interpreted as nature itself. It is more accurately described as a simplified educational growth model consisting of discrete ice cells, a discretized vapor field, and local growth rules.

Parameter exploration as a numerical experiment

The Excel implementation includes a control sheet from which students can change parameters, run the model, observe the resulting structure, and compare different patterns. Different parameter settings can produce substantially different structures. Students can therefore study the sensitivity of the model to individual parameters.
The educational goal is not to search for the one “correct” snow crystal or simply to tune the parameters until the simulation produces the most visually attractive result. Instead, students investigate which assumptions, parameters, and processes affect the simulated structure. In this sense, the simulation itself becomes an experiment. Parameter values can be changed systematically, results can be compared, and hypotheses about the behavior of the model can be tested.

This approach also makes parameter sensitivity and model dependence directly visible. A visually realistic result does not necessarily imply that the model is physically complete or that its parameters uniquely represent natural conditions. Such comparisons provide an opportunity to discuss the distinction between reproducing a visual pattern and representing the physical processes responsible for that pattern.
Learning with models and learning about models

The broader educational aim is therefore not only learning with models, but also learning about models. Students can be encouraged to ask four basic questions:
- What is represented?

- What does the model simplify or omit?
- Where do limitations and uncertainty come from?
- How should we interpret the results?

These questions lead to what is described here as model literacy. A central principle of the activity is: Do not let the model become a black box. Students do not need to understand every mathematical or computational detail of a model, but they should have some idea of what the model is doing, what assumptions it contains, and how those assumptions influence the results.

This point is becoming increasingly relevant as numerical models—and tools capable of generating or running models—become more accessible. Ease of producing a simulation does not remove the need to understand its assumptions and limitations. On the contrary, greater accessibility increases the importance of learning how to interpret model output critically.

Beyond snow crystals

The relevance of model literacy extends well beyond snow crystal growth. Modern weather forecasts, typhoon predictions, and climate projections depend heavily on numerical models, but the sources and treatment of uncertainty differ among these applications. Weather prediction is strongly affected by uncertainty in initial conditions and chaotic behavior; typhoon forecasts commonly communicate uncertainty through ensemble tracks and forecast cones; and climate projections include uncertainties associated with models, natural variability, and future scenarios.

The specific methods differ, but the underlying educational question remains the same: How should we interpret model results? Members of the public do not need to solve the governing equations of atmospheric models, but they benefit from understanding what a model can—and cannot—tell us.

Snow crystals provide a small, visually accessible system in which this idea can be explored directly. Students can observe a natural phenomenon, reproduce selected aspects of it in a controlled laboratory setting, construct progressively different numerical representations, modify model parameters, and compare the resulting structures. Through this sequence, the distinction among nature, physical models, and numerical models becomes explicit.

The educational progression can therefore be summarized as:
Beauty → Observation → Experiment → Modeling → Model Literacy → Connecting with the Public

Snow crystals are not merely the subject of the lesson. They serve as a gateway to understanding how meteorology explores nature through observation, experimentation, and modeling—and how the results of those approaches should be interpreted and communicated.

References

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