Pedagogical Aspects of Teaching Modeling by Means of Doppler Effect; Situations Using parallel Physical and Mathematical Models

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Abstract

The Doppler effect is special pedagogically because it can relatively easily develop modeling competency as an interdisciplinary skill, and because the Doppler effect is extremely simple to state and to model. Doppler modeling starts with two basic types: (a) physical models showing the physics of the process(es) involved, and (b) mathematical models that "live" in abstract space-time graphs. Both of these basic types involve using prior knowledge to connect various skills together from different student "mental boxes" (verbal, pictures, some simple rules or properties of gases, and liquids and solids, diagrams, elementary geometry of triangles and parallel lines, and working with linear graphs). These skills are further reviewed and developed during the Doppler modeling lessons, as is the skill of changing representations, or of translating models from one domain to another, e.g., physical models into first graphic models and then math models – and vice versa. Both the basic types can be creatively manipulated for different contexts. The mathematical models "live" in the abstract space of simple two dimensional space-time graphs. The modeling exercises and examples are a neat way to awaken, motivate and develop student skills and interests. The modeling process proceeds from the simple stationary case to the full Doppler scenario case in many different contexts. When the students see how the models change from context to context, how they are evaluated, and where their limits are, they develop modeling competences, which are transferable to other disciplines, and, they "get the big picture". As an added attraction, we should mention that the modeling development was developed/designed to be consistent with Bloom's taxonomy of the cognitive domain, and was executed by an author who spend most of his career modeling complex systems, with over twenty publications just on fairly specific models in advanced design.

Developing Modeling Competency In General

It is hoped the approach to the modeling process and models described herein will become a major example for effectively and concurrently teaching Doppler effect models and modeling in general, concurrently in order to develop the very important and desirable interdisciplinary modeling competency in students, as mandated by the Danish Parliament in 1999 for better education (as described and discussed in [1]). When teaching the beginning of modeling to students in middle and early high school it is important to play with the models so that they get familiarity with their advantages and limitations. To do this it is important to show that the models taught/used are not static things "just to be used without question", by "turning the crank" to churn out numbers, curves and/or tables. Instead, models are to be examined by the student herself, with the magnifying glass of her own mind (minds-on, for modeling). She must not only hear and see, say and write, but most importantly DO (Dale's Cone of Experience, as quoted in [2]). This can occur with sustained/ guided play. It demands that the student comes to see that models, like things, are analyzable, challengeable, changeable, malleable, adaptable, generizable, etc. On this view, models are like most toys, gadgets, materials that we can play with in the above manner, but the play must be actively performed with interactive student participation [3, 4] and exploration. This is very important. The pedagogical principle of learning by experiencing, constructing and interpreting leads the mind to form the "space of reasons" that contains the creation of conceptual relations. These involve a feedback loop process between theoretical constructs and experiences (D.Bakhurst, 2001 as quoted in [3]). The important thing for modeling is that models are easier to play with than most concrete objects, because they can be changed at will. I.e., the player/gamer can consider unreal conditions, such as assume unrealistic values of parameters – just for fun, or for curiosity. They can even be simulated for easier processing. Life simulations have been used to teach the Doppler case in a variety of guises and locations [5]. Yes, this play, can be fun and exciting, as most physics [3, 4]. It brings its own reward by means of the feedback loop process to provide the foundation for developing modeling competency. The play with models involves changing contexts, stretching limits, making note calculations on napkins, and even changing the meaning of words along with the contexts. It also involves also making mistakes and corresponding feedback to improve skills and understanding. Just like all creative processes, so physics too involves making mistakes, and these are to be stressed [4]. Playing with modeling as recommended herein teaches students not only to be bold and fearless about error, but also to be careful and to check their work with reasonableness and consistency checks. The Doppler effect provides an opportunity to teach not only a fundamental law of physics but also the modeling process itself in ways that are fun and relevant to the students. I.e., the Doppler effect model is amenable to a lot of fairly easy manipulations that will lead students in an important, exciting and fun way to realize modeling as an interdisciplinary competence. As shown below, four of the taxa from Bloom's taxonomy guided and progressively developed the material presented herein: Explain / Comprehend, Use/Apply, Analyze/Investigate and Create/Modify.

The Doppler Modeling In Particular

The case of stationary source and observers is used to as prior knowledge and to develop vocabulary and concepts of the relevant processes. The graph model is simple to develop. Next, the case of moving source, and moving observer is considered first physically, then graphically in Space-time, and finally mathematically. The simplest such model is a linear kinematics (D = VT) model living in two dimensional space-time graphs, where one axis is the time axis, and the other is the distance axis Bloom's taxa used where: A) Explain / Comprehend: The explanations for the development of the model involve space time graphs, the geometry of parallel lines (these represent the world lines of equi-phases of the wave phenomena), and congruent triangles. The classical Doppler equation becomes a theorem in Euclidean geometry of equally spaced parallel lines being "cut"/crossed by a skew line! The period of the parallel lines is the inverse of their frequency of cutting the time axis. The changed/ shifted frequency is the rate at which the skewed line cuts the parallel lines. That is all there is to stating the simple classical Doppler effect graph model in words! The math model involves translating the words into mathematical symbols. (B) Use/Apply: Use the Doppler effect for distant measurements inferring the velocities of cars on a freeway, or the pulsations of the surface of the Sun, and detecting the rotation of the planet Venus that is perpetually cloud covered, by reflecting radar signals from the opposite rotations at either end. (C) Analyze / Investigate: This first involves the categorization of the Doppler models. Then it involves analysis of the specific models to see how they can be changed, improved, and played with. Next, it involves obtaining theorems about how the data which upstream and down stream observers can deduce when combining their observations. NOTE:

This is called "data fusion" and yields much more information to the sharing observers than they could deduce just from data that depends just on measurements that they make only from their own point of view. (D) create/modify : The simplest modification is to obtain the frequency shift of the beeps from a fog horn in thick fog. Next to consider the reflection off moving surfaces. Then, kinematics analogy where runners convey information along similar, but not necessarily straight, pathways to the upstream and down stream observers (more precisely, "information gatherers"), where runners running at equal speeds, replace the wave phenomena. (3) Consider an approaching (receding) object, like a train, and model its worldline on a space time graph. The result is that observers see the two ends (back and front end) simultaneous to their senses, but from different times! Question: Why? Answer: The time that the light travels is different from each end. Yet to appear simultaneous to the observer they must reach her concurrently. Even though the "length shift" equations are the same as the Doppler frequency shift equations, the case here only "roughly" a spatial Doppler effect. Rather it is a new entity, one example of a "top case", in Schola Ludus terminology [6] that comes almost naturally with a creative playing with the modeling.

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