Subject:
In textbooks the concept of coherence is explained in various different ways. The following citations are taken from different books:

(1) “Wave trains which interfere with one another are called coherent, those which do not interfere are incoherent.”

(2) “Two wave generators, which produce a permanent interference pattern are called coherent. In order to do so they must oscillate with the same frequency and a constant phase difference.”

(3) “For an extended light source, e.g. a glowing filament, the wave trains emanating from different points of the filament and striking the eye are incoherent, i.e. they have completely different phases and directions of polarization.

(4) “Only light which starts from one point of a light source, can be brought to interfere, after being splitted and traversing different ways.”

(5) “Since the light that is spontaneously emitted by a hot body is radiated from atoms that are independent from one another, it is excluded that two different light sources incidentally execute the same oscillation, i.e. emit coherent wave trains.”

(6) “A slit emits coherent light as long as for its width $d$ and for its angle of aperture light cone $2\alpha$ holds: $d \cdot \sin \alpha < \lambda/2$.”

Deficiencies:
Not only high school students but also university students have problems with the concept of coherence. The definitions cited above show that this is not wonder. Some of them are hard to understand by themselves. But things get particularly difficult when trying to reconcile these statements with one another.

In the following, the numbers refer to the numbers of our citations.

What is the object to which a statement about coherence refers? According to the citations (1), (3) and (5) it refers to the relation between two “wave trains”. But what is a wave train? The whole wave? Or part of it? Which part?

According to definition (2) coherence expresses the relation between two wave generators. It is said, that these have to oscillate with the same frequency and a constant phase difference. Does that mean that there are oscillators that can oscillate with the same frequency and a phase which is not constant?

Citation (6) attributes the coherence simply to the light.

Now, the question is if these definitions are only different formulations of the same fact or do some of them contradict one another?

Definition (3) tells us that only light which emanates from one point is coherent. Definition (4) makes a similar statement. But what is meant by two different points? Is there a maximum distance which is allowed? Definition
(5) says it more clearly: Light which comes from different atoms cannot be coherent. However, it is well-known, that light from a distant star is used to determine the star’s diameter by means of Michelson’s stellar interferometer. In this case light interferes which comes from sources that can be a million km distant one from the other.

**Origin:**
All the sentences (1) to (6) make statements either about how to create coherent light or how to demonstrate coherence. None of them tells us what is the nature of coherent light. But if we know only the property or nature of the source, how can we judge the coherence of a light field whose sources are unknown or unspecified, for instance the water waves on the ocean?

Here, we note the tendency to describe the generation process or the detection process of a phenomenon instead of the phenomenon itself. Usually these processes are more complicated than the real phenomenon. To understand how a bicycle works, we do not need to know the production process in the bicycle factory. In order to understand what a sound wave is, we do not need to know the working principle of an organ pipe or the human hearing.

Another cause for some incongruities is the tendency to consider a phenomenon as understood only when it is reduced to a statement about the behavior of some particles. Coherence is a phenomenon which can perfectly be described by means of classical wave theory. When looking for an interpretation in the context of quantum phenomena one easily gets trapped in the brushwood of models and interpretations.

**Disposal:**
Let us begin with two general remarks concerning the concept of coherence:

1. Coherence, which can be more or less pronounced, is a property of the light. It is understood that the light owes its properties to a light source. But that does not mean that coherence or incoherence is a property of the source.

2. Coherence is a local property of the light. That means that a given light distribution can be more coherent at one place than at another. So the spatial coherence of the light that is emitted by a star is minimum at the star’s surface and is almost perfect (maximum) here at the Earth i.e. at a great distance from the star.

When we say that coherence is a local property, we do not mean that coherence can be attributed to a point in the sense of mathematics. (In this sense no physical quantity is local.)

Coherence can be explained or defined in various ways. It manifests itself in each theory which is used to describe the light: geometrical optics, classical wave optics, the thermodynamics of light and quantum electrodynamics. Since it is our goal to explain the concept to a beginner, we will choose the simplest of these theories, i.e. geometrical optics. After this we will hint at how this explanation translates into wave optics. We advise not to try an explanation on the atomic scale at the school. This is a subject for the University.

We limit ourselves to evaluate the degree of coherence qualitatively. Let us try to describe the light in a small domain of space just in front of us. Which
kind of light rays are crossing this space? We consider four situations which are particularly simple.

We are in the middle of dense fog. Our space domain is crossed by light rays of all directions. The light is a mixture of light of all spectral colors, indicated in Fig. 1 by differently dashed lines.

Next we assume it is night, dense fog again and there is a street lamp that emits monochromatic light. Again the light in our space domain comes from all directions, Fig. 2.

In our third situation it is night, no fog, no moonlight, no starlight. At a great horizontal distance there is an incandescent light source. Now all light rays which cross our space have the same direction, but it is light with many different spectral colors, Fig. 3.

Finally a situation similar to the one before, but with a lamp that emits monochromatic light, Fig. 4. Now all rays have the same direction and all the light has the same spectral color.

The light in fig. 1 is completely incoherent. That of fig. 2 is called “temporally coherent”. Thus temporal coherent light is monochromatic light. The light of Fig. 3 is spatially coherent. Thus, spatially coherent is the opposite of diffuse. The light of Fig. 4 finally is temporally and spatially coherent.

Here yet an analogy or allegory that one may tell to the students. We consider a crate with apples. The apples have a great range of colors and sizes. We want to classify them. We begin by assorting them according to their size into 10 different boxes, each box for a given size interval. Now in each box the apples are uniform with respect to one of our criteria, i.e. size. Next we assort the apples of each box in one of 10 smaller boxes accord-
ing to color. Altogether we now have 100 boxes. In each of these boxes the apples are uniform with respect to both our criteria size and color.

The similarity between apples and light goes even further. It is obvious that we can get uniform apples from the initial crate only by sorting out those apples that do not correspond to the desired size and color. It is not possible to transform the multi-color multi-size apples into uni-color uni-size apples, in the same way as it is not possible to transform incoherent light into coherent light – which would mean destruction of entropy and thus violate the second law.

One can, on the contrary, grow trees that produce uniform apples from the beginning. In the same way we can employ a light source that produces coherent light from the beginning, i.e. a laser.

At the end a word about the wave optical description of coherence. Light is temporally coherent when the dispersion of the magnitude of the $k$ vector is small, it is spatially coherent when the angular dispersion of $k$ is small. It is easy to tell the coherence by looking at a waves, say for instance the waves on the surface of a lake. There may be sections of the wave field that look like sine waves. These sections have a certain lengths and a certain widths. The length is a measure of the temporal coherence, the width is a measure of the spatial coherence.

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