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Dynamic images to address conceptual nodes about mechanical waves: Example materials and preliminary results of the experimentation of the teacher training module IMAGONDE

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Summary. — In the framework of the 2002-03 project "Fisica per la Formazione Culturale - FORMazione Insegnanti" funded by Italy ministry of Education, a set of training materials, focused on mechanical waves, has been developed. The core of the materials is represented by animated images purposely designed in order to: 1) address intrinsically dynamic aspects of one-dimensional impulses/waves propagation on a string; 2) have the trainees reflect upon students' difficulties in reading/interpreting static images (as the ones which are featured in common textbooks) and animations. In this paper we discuss example materials concerning transversal impulses on strings to address conceptual nodes such as: 1) configuration of the string at a given time and its abstract representation; 2) displacement *vs.* time graph of a string element and its abstract representation; 3) relationships between the two abstract representations; 4) modelization of mechanical wave propagation in one dimension. Moreover the results of the experimentation of the training materials in the framework of the Post Graduate School to Became Physics Teacher in Secondary Schools are presented and commented.

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1. – Use of images in physics education

The use of images in science education and in scientific communication is nowadays fully accepted and adopted: almost all physics textbooks used in secondary school feature many "still" images (*i.e.* photos, schemes, symbols, diagrams, mathematical graphs) to support text exposition. In the meanwhile, due to the spreading of Internet (starting from 1997-1998), also "dynamic" images/animations (as, *e.g.*, simulations, short movies, Java applets) have acquired an increasing role in science education contexts due also to the wider scenarios opened by e-learning. The debate on weather still images are effective in science teaching is still open and research results often disagree [1-6]; moreover, in a recently closed European Project([1]), a study about students' difficulties in reading and interpreting such images has been carried out; some of the results can be found in [7-10]. As far as dynamic images and animations are concerned, many research have studied their effectiveness [11-16]: although often considered as more effective than still images [17, 6], some research results [18] claim that dynamic images and animations can be almost ineffective for learning. Despite the debated reasons, we believe that they are a useful tool to address students' difficulties in those phenomena that are intrinsically dynamic as wave propagation is. Actually, in the following, we will focus on images, both still and dynamic/animated, to address very well-known conceptual nodes concerning propagation of mechanical waves [19-21]. Amongst these we recall:

– existence and meaning of non harmonic travelling impulses;

– representation of a transversal wave in terms of $y(x)$ and $y(t)$, where y is the vertical displacement of a string element, x the abscissa along the string and t the time;

– meaning of the velocity of a travelling wave *vs.* velocity of the string element;

– meaning of the wave function.

2. – Dynamic images and the study of mechanical waves

The study of mechanical waves, due to their intrinsic dynamical characteristics, can be addressed integrating usual presentation with interactive/animated images. Many applets and simulation environments can be found in internet. The main topics addressed are the basics concepts of wave propagation as, *e.g.*: 1) transversal and longitudinal waves; 2) reflection and refraction; 3) interference and diffraction. Often the simulation applets are interactive, *i.e.* the user can change one or more parameters by moving sliding bars and/or check boxes. Moreover applets are sometimes suitable for an off-line use. On the other side, explanations are usually very scanty and seldom there is a description of the model used for the simulation. This can lead to the same risk that can be envisaged when using a commercial experimental kit, where teachers, specially those who are not skilled enough in laboratory work, often end up implementing only the suggested activities. All these aspects suggest that one of the main goals of teacher training, in a research informed framework [22, 23], should be that of familiarizing teachers-to-be with on-line iconic resources and at the same time favoring the self-design and organization of materials to support the implementation of didactic paths. The set of teacher training materials called IMAGONDE, produced within the framework of the Italian Ministry of Education funded project "Fisica per la Formazione Culturale - FORMazione Insegnanti" [24], has been developed by our research group, also on the basis of the results obtained in the STTIS project, mainly to increase the trainees awareness of the didactic potentialities of both still and dynamic images and to favor production and implementation of original materials focused on mechanical waves. In the following we briefly resume the main features of IMAGONDE and describe some of the results of the experimentation carried out during the course of Physics Education II, in the Post Graduate School to Became Physics Teachers in Secondary Schools. The data collected have been questionnaires, trainees portfolios and final works discussed at the end of the course.

([1]) STTIS (Science Teacher Training in an Information Society) Project involved five European nations: France, Italy, Norway, Spain and UK.

3. – The training materials: IMAGONDE

The set of training materials, mainly devoted to teacher trainers, propose a didactic path on the propagation of a transverse impulse (saw tooth, smoothed scalene triangle, trapezoid, sinusoidal shaped) on an infinite massless string, travelling at constant velocity. Macromedia Flash and Microsoft Powerpoint animations have been specially designed to address the iconic relationships between the graphs of the displacement of the string element centered on x^* *vs.* time (from now on $y(t)$) and the configuration of the string at fixed time (from now on $y(x)$); the $y(t)$ and velocity *vs.* time of a string element (from now on $v(t)$); the $y(x)$ and the distribution of the velocities of string elements *vs.* their abscissas at a fixed time, (from now on $v(x)$). Macromedia Flash has been chosen since it is a very flexible, platform-free and a powerful tool for any professional video-graphic application. The reason for using Microsoft Powerpoint, often used by many secondary school teachers, is to stimulate trainees to an advanced use of animation features of the software. All the animations are inserted in web pages, available for downloading and for an off-line use. The materials comprise also questionnaires to be submitted to trainees, research-based documents and suggestions for implementing the proposal. Here in the following we describe briefly example materials of the animations, the questionnaires and supporting research documents.

4. – Example materials

4·1. *Animations.* – One major advantage of using animations to address mechanical waves contents is the possibility to well distinguish between progressive and regressive impulses travelling on a string (otherwise difficult to do only with still images). Here we show how, in the case of a regressive wave and for smoothed scalene-triangle–shaped impulse, the relationships $y(x) \rightarrow y(t)$ and $y(t) \rightarrow y(x)$ are determined.

- Figure 1 shows a frame of the animation that allows to address the passage from the $y(x)$ graph to the $y(t)$ one. Amongst the iconic elements used we remind that: the arrow represents the direction of propagation of the impulse; the color change (in the animation) of the rectangle represents the passing of time; the circles and squares represent the vertical displacement of the string element x^* as the wave front reaches it. Such displacements of x^* are reported in the $y(t)$ graph at times t_0, t_1, t_2, t_3, t_4.

- Figure 2 shows how to determine the relationship between $y(t)$ and $y(x)$ graphs. The construction goes as follows: as time goes by, string elements with greater abscissas are reached by the perturbation *before* string elements with smaller abscissas. To understand the construction, one should refer to the shape of the impulse and to the fact that (referring to the figure) when the string element at x^* is at rest (after the impulse has passed it), the string elements at x^{**} and x^{***} have vertical displacement different from zero.

4·2. *Questionnaires.* – Three questionnaires have been designed to support the training intervention. The didactic goal is twofold: to elicit student teachers' naive ideas about wave propagation and address common learning difficulties; to increase trainees' awareness of iconic difficulties when reading images/animations concerning mechanical waves propagation. Excerpts are reported in the following section. As an example we report here one of the questions presented in the questionnaire.

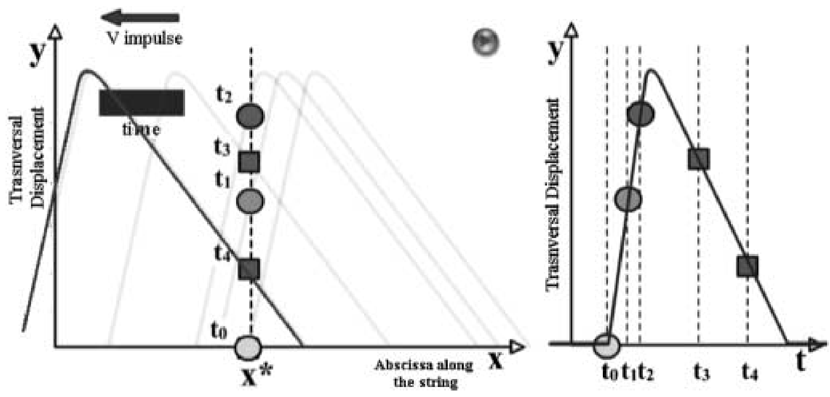

Fig. 1. – The figure shows the relationships between the $y(x)$ and $y(t)$ graph.

– "Q2". The image (see fig. 3) represents the distribution of samples of a recorded sound as a function of time.

Describe the physical phenomenon that the image represents, the meaning of the axes variables and of the iconic codes used.

Such a question can be useful to investigate the trainees' ideas about abstract representation of real sound waves and to familiarize them with graphs usually not present in school textbooks.

4·3. *Research documents*. – The set of IMAGONDE materials comprises also a bibliography about conceptual nodes in addressing wave propagation in order to get teachers-to-be acquainted with up-to-date research results. Moreover, some results about secondary school students' interpretation of still images obtained in the framework of the STTIS

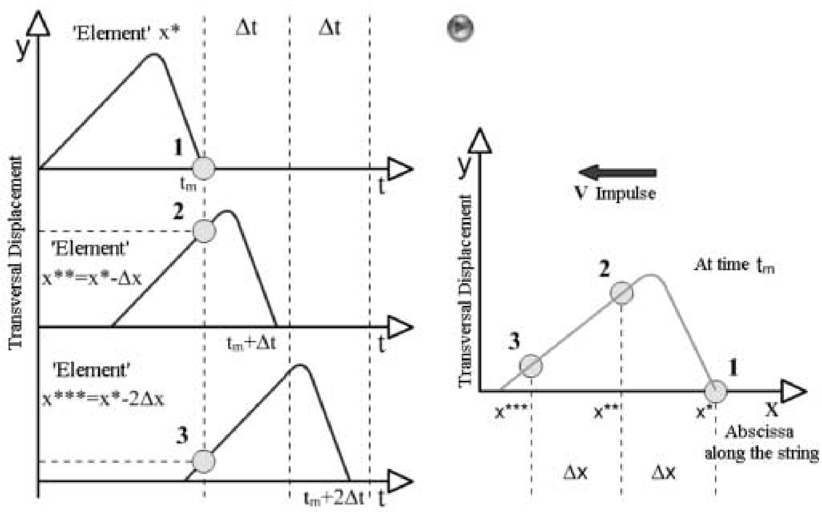

Fig. 2. – The figure shows the relationships between the $y(t)$ and $y(x)$ graph.

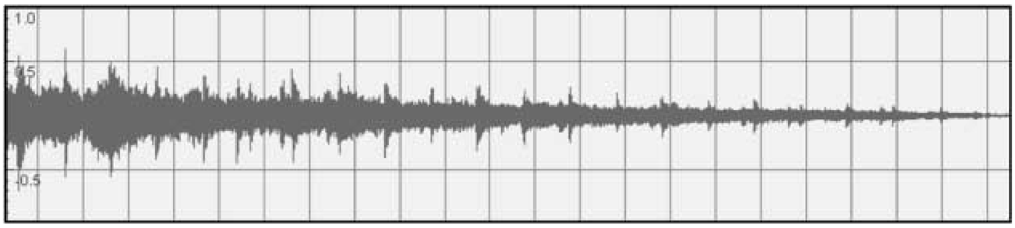

Fig. 3. – Image presented in the Questionnaire "Q2".

Project, in which our research group has been involved, are presented briefly. The presented results refer mainly to reading of real-time kinematics graphs: they can be useful when dealing with images of, *e.g.*, sound waves as represented by common shareware software (see fig. 3).

5. – Experimentation of IMAGONDE materials

5·1. *General aspects.* – About 60 trainees have participated to the experimentation of IMAGONDE materials for a total of 12 hours of in-presence sessions. The phases have been:

1. the questionnaires have been submitted and analyzed in order to have a picture of the initial situation of trainees' previous content knowledge about wave propagation and awareness of potentialities/difficulties of images and animations in physics education;

2. the IMAGONDE proposal has been examined in detail;

3. assessment activities have been assigned to trainees. Such activities concerned basically the design of a didactic path for secondary school students about the propagation of waves, focusing on aspects not addressed during the course. The use of supporting laboratory work concerning the disciplinary topic addressed, as well as the use of still and dynamic images and/or software simulations was required.

5·2. *Questionnaires.* – The trainees' answers to the questionnaires have shown that, at the beginning of the training session, some difficulties about wave propagation existed and had to be addressed. The hours devoted to the experimentation of IMAGONDE have been designed also to address such difficulties. Analysis is still in progress (35 questionnaires have been collected) but here we report some of the answers to the question "Q2" reported above. Almost all (31 out 35) the trainees have identified correctly that the amplitude of the sound is decreasing. Another correct answer is: "*I think that the variables on the axis are pressure and time*", given by two persons. On the other hand, many answers reveal some difficulties, triggered mainly by iconic aspects of the graph: "*I think that the graph represents a sound source that is moving away..*"; "*The peaks suggest that this is not a clear sound*"; "*The figure makes me think of a loud sound*"; "*..it seems that the sound has a very high frequency*".

5·3. *Features of the assessment activities.* – In table I we resume the topics addressed by trainees' proposed activities and their distribution.

TABLE I. – *Topics addressed by trainees'proposed class activities.*

Characteristic of mechanical waves propagation and representation	3
Transversal and longitudinal mechanical waves	3
Sound waves and their propagation	3
Water waves	3
Characteristics of electromagnetic waves and light propagation	3
Interference and diffraction of light	3
Signals representation and analysis	2

The trainees activities have been evaluated and analyzed using a grid designed taking into account the didactic objectives of the training materials (see table II).

Analysis is still in progress but preliminary results show that:

- *Type of images proposed*: all the class activities proposed by trainees featured both still images and animations.
- *Use of images*: extensive use of still images has been made by many groups (17 out of 20). We have evaluated them sufficient in 4 activities, good in 6 proposed activities, poor in 7 cases.
- *Use of animations/software simulations*: animations (downloaded internet applets) have been included by 9 groups in their class activities. Their use has been evaluated sufficient in 4 cases, good in 2, poor in 3 cases.
- *Quality of the image*: such issue has been not adequately addressed by trainees; in many cases images lack captions and/or explanations, and iconic features have often been disregarded as tools to facilitate students' comprehension of physics topics addressed, except in some cases described below (see subsect. **5**.4).
- *Awareness of iconic features difficult to read and interpret*: awareness of iconic difficulties has been evaluated low in 13 cases, sufficient in 4 cases.
- *Integration between animations and laboratory work*: such issue has been evaluated globally very low. Only some groups (3-4) proposed qualitative observations of wave phenomena using slinky, strings, rough ripple tank.

TABLE II. – *Evaluation grid of trainees'proposed class activities.*

	Still	Animated
Type of images proposed		

	Poor	Sufficient	Good
Use of images			
Use of animations/software simulations			

	Low	Sufficient	High
Quality of the image			
Awareness of iconic features difficult to read and interpret			
Integration between animations and laboratory work			

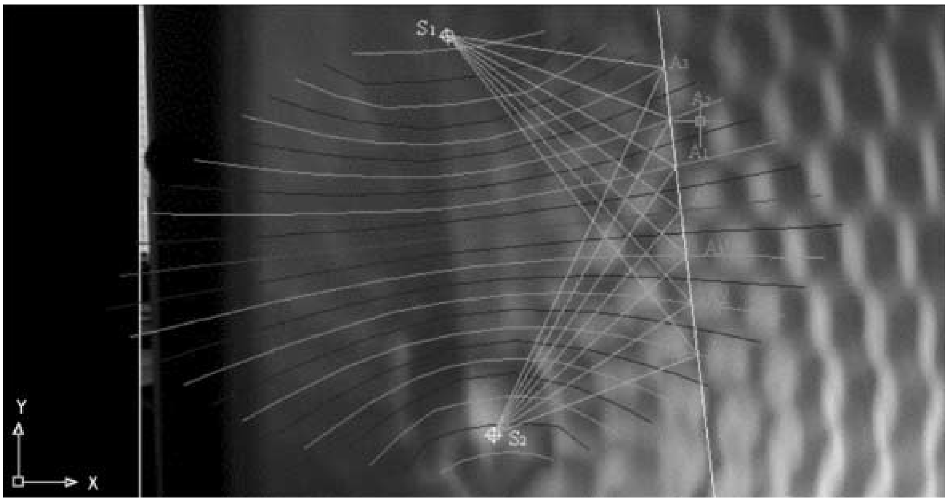

Fig. 4. – Ripple tank interference figure with Antinodal lines and points evidenced.

5˙4. *Trainees iconic documents*. – As said in subsect. **5**˙3 some trainees proposed, for class activities, autonomously designed supporting images and animations about wave propagation. In particular we describe here two images designed to support a proposed laboratory session with ripple tank addressing interference of waves in water. In figs. 4 and 5 a way is shown to address the construction of nodal and antinodal lines for the interference of two sources of circular waves propagating in the ripple tank.

We focus here on iconic features of both images. Symbolic and real entities are here mixed: on a photo of the interference figure produced in the ripple tank, lines and labels are drawn in order to clearly indicate the position of the two sources (labelled S_1 and

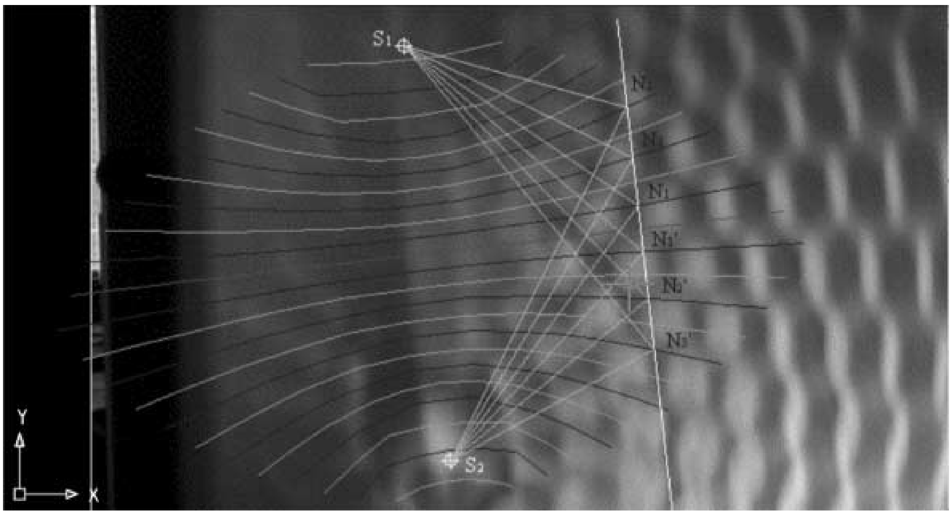

Fig. 5. – Ripple tank interference figure with Nodal lines and points evidenced.

S_2 in both figures) and of the nodal and antinodal points (labelled A_1, A_2, A_3 in fig. 4 and N_1, N_2, N_3 in fig. 5). Antinodal and Nodal lines are here indicated by lines of two different greys (colored lines appear in the animation). Part of the didactic path was devoted to the explanation of the iconic codes adopted and how they can help addressing interference characteristics. All the images have been produced with Autocad.

6. – Conclusions

In this paper we have presented the set of training materials called IMAGONDE, devoted to address content areas about mechanical waves propagation, in which well known teaching/learning difficulties exist, by way of purposely designed images and animations. Iconic features are exploited also in order to raise teachers-to-be awareness of possible/plausible students' difficulties when reading such images/animations. The framework and the evaluation criteria of a first experimentation of such materials have been briefly reported; preliminary results have also been described in order to evaluate the effectiveness of the proposal in teacher training programs. The collected data support the conclusion that some disciplinary difficulties of the trainees about waves propagation have been addressed and sometimes overcome, as evidenced by the analysis of the proposed class activities, although still some disciplinary nodes remained unresolved probably due to the narrowness of the content area addressed. As far as the iconic aspects are concerned, some of the presented documents show an increased awareness of the use of images' iconic codes, although in many cases images are only used with the aim of reducing the load of a text-only presentation. Java Applets have also been exploited by the trainees, but many times they were not well integrated within the class activities proposed. Such results suggest and encourage an enrichment of the IMAGONDE materials in order to improve the trainees' skills in designing class activities which feature text, still images and animations in a more coherent and effective way.

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