The subject of waves in a new approach introductory steps of a Design Based Research (DBR)¹

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Abstract Based on years of teaching, our team aims to elaborate a modern experimental manual with a modular structure meant to entwine the features of a traditional book on paper support with the advantages of an e-book. The chapter on the Wave Theory has been written as a start-up. In our vision, the core material of the manual is targeting those high-school students who do not wish to study Physics on a higher level, meanwhile the extensions to the lessons (such as the simulations, high-level extra information and any other attractive topics etc.) are for the students who are interested in Physics and who are thus given the possibility of a more profound study. The traditional manual would be designed to cover the core material, and the extensions would be made accessible via smartphones, as well as the QR-codes placed in the lessons. The webpage that has been added to the online version includes the written lessons, the extensions being placed into so-called boxes. Approach to the chapter largely differs from any previous approaches as the wave types are presented along with the description of the related wave phenomena. Practicality and efficiency testing of the webpage is ongoing in a rather close circle via questionnaires and a multiple choice test, the manual to be continuously improved and amended subsequent to the feedback we receive and according to our own teaching experiences.

1. Introduction

These days we can hear it more and more often that a significant segment of the textbooks are unable to meet the growing expectations of the last decade. In other words, there is no simple answer to the following question: What does a good textbook look like? There are several international research institutes and associations involved in the process, such as the GEI (Georg Eckert Institut für Internationale Schulbuchforschung), the IARTEM (International Association for Research on Textbooks and Educational Media), the ILZ (Interkantonale Lehrmittelzentrale), the ZUSE (Zentrum zur Unterstützung der wissenschaftlichen Begleitung und Erforschung schulischer Entwicklungsprozesse), and the American Textbook Council. These are all attempting to come up with a book which is used by both, teacher and student with great enthusiasm and which encourages the active involvement of all the students. The manual should be fun to read, easy to understand and it should facilitate a thorough comprehension. It should not contain too many facts and data. It should be designed to promote independent student activities and assist the implementation of differentiated class work. A good textbook is designed to allow the acquisition of new knowledge via independent study, corresponding to the special, age-related characteristic features of the students. Therefore, the implementation of the appropriate textbook would strengthen to a great extent the possibilities, as well as the efficiency of the educational efforts [1].

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Historically speaking, the function of the textbook is to help home-based learning subsequent to the schoolwork. However, this primary function has been accompanied by new, mostly formal expectations in the past years. We expect from a school manual book to raise students’ interest. Therefore, some textbooks are stuffed with wonderful and brilliant photos, funny cartoons, curiosities, which have very little to do with the topic in question. It is questionable whether such visual aids can really facilitate the consolidation of a certain topic (e.g. actual learning), or, in other words, if such images are really able to carry a genuine functional role. Would it not be more appropriate to provide an essential visual caption of the physical content – in a physics textbook – in the form of a graph, vector diagram, and to highlight the point in an experiment, etc., in order to accommodate the more and more predominant visual inclination of students? Up-to-date novelties become easily outdated, therefore, the impact of the efforts made to enhance the students’ interest might miss target.

It takes a lot of effort and good intentions to include reading tasks into a textbook to broaden the students’ horizon and their insight. The question is, how many of the 17-18 years old students will actually read such lengthy passages when they have to learn 5 or 6-page (or even longer) lessons? Due to the countless requirements and expectations viewing content and format, the series consisting of subsequent textbooks are usually about 200 pages or more. It should be noted that at the time being, even the foreign textbooks are also still extremely long, despite of their outstandingly emphatic presence of Internet based supplements.

2. Concept
It is our conviction that instead of stretching the limits of the conventional textbooks more it is more advisable to look for some novel solutions. No doubt, the radical long-term solution will be achieved by complex tutorials installed on computers. This approach, however, can already be applied while maintaining the printed textbook format as well.

Our concept is based on a textbook containing only the core material of the physics curriculum with functionally associated figures intended explicitly to facilitate learning. All the other important tasks assumed currently by textbooks are outsourced to the Internet. Using a QR code inserted to the appropriate place in the printed matter, the student gains access to the related special materials within seconds.

In order to fine-tune the concept further, the team prepared a chapter of a textbook. The chapter selected, for writing up deals with Wave science. Phenomena related to waves belong to the predominant, yet for the students it was difficult to comprehend and acquire parts of the material taught in secondary and primary physics classes. Processing this field can be seen as interesting in particular because it connects classical chapters of physics – encountered on a daily basis– and the less spectacular portions of modern physics. The chapter intends to ensure stable foundations, a competency level in the use of elemental mathematical techniques, a clear understanding of concepts and notions, a recognition of essential correlations, practical experiences gained in problem solving and a substantially higher level than the current one of analytical thinking. We would furthermore like to see students enrolling in universities empowered with the techniques necessary to learn natural sciences and able to read and understand more complicated science texts.

We are convinced that this can be achieved only by practicing the basic elements of scientific thinking, such as observation, experimentation, concept building, a creation of theory, as well as the basics of inductive and deductive thinking through simple models and a body of knowledge.

The development of the textbook concept is anticipated to be accomplished in a gradual manner, first tested in a narrower, later in a wider scope, with the experiences and lessons incorporated. This way it can be studied how an e-text book can be used for teaching.

3. Usability and benefits of the e-textbook
Digital learning materials fulfil their innovative function when they do not represent a different medium only, but take advantage of such novel (digital) solutions which their hard copy counterparts are unable to perform in their efforts to promote efficiency and joyfulness of the learning process. As a rule, digital
learning materials are expected also to contain instructions of use and methodological assistance to teachers.

The use of digital textbooks provides the opportunity to integrate the design and implementation of multimedia contents, interactive elements, automatic measuring, evaluating mechanisms, and custom tailored contents. Involvement of multimedia contents in education and their application in the world of the textbooks serves complex objectives. Information processing strategies of students have undergone a change in the world of multimedia devices full of stimuli. Their attention is drawn to colourful and rapidly changing information including more and more senses in the procedure of processing. Since in the out-of-school world students are accustomed to the presence of such information, it is indispensable to constantly transmit multimedia information also in the learning procedure if their attention is to be raised and maintained [2].

Appropriate digital tutorials allow multidirectional communication, activity and interaction between humans and machine. Instead of being characterised by passive reception when acquiring learning materials, they trigger activities with an intention to motivate. Multimedia contents providing the possibility for students to intervene into the outcome of events and phenomena upon activation are designed to arouse the desire to learn. The pedagogical goal is to discover learning based on experiences, which may enhance the rate of comprehension of the learning material in addition to motivation. [3]

Due to modern technology digital textbooks may also contain exercises in addition to the curricula, the solution of which, once solved by the students, can be checked through self-checking possibilities. Such an option allows the implementation of a number of educational purposes. Following acquisition of the material the student may receive tasks to assess the success of the learning process, to ensure application of the knowledge acquired and induce knowledge transfer processes. Through such automated evaluation self-regulation learning competence can be developed, which constitutes an integral part of the implementation of the desired lifelong learning paradigm. Thanks to the technology, the tasks and exercises may also contain multimedia and interactive elements, exerting a positive, motivating effect on the willingness to solve problems.

An important aspect of ensuring a personalised custom made learning environment, is the possibility granted to teachers to create digital elements in the curricula and to expand, and supplement the permanent contents of digital textbooks. If the provision of communication platforms implementing teacher-student, student-student and teacher-teacher interactions constitute a part of the digital solution, this may play an important role in the enforcement of customised educational strategies and promoting cooperation processes.

4. Design-based research - DBR
When you intend to develop a new educational material aiming at the creation of “usable knowledge” containing practical problems as well, design-based research (DBR) may be instrumental [4-7]. DBR assessment logic includes induction (mapping of patterns), deduction (verification of theories and hypothesises) as well as abduction (searching the most appropriate of the available explanations to interpret the results obtained and rely on it henceforth). DBR is used quite often to solve practical teaching problems in the field of educational technology with the aim to expand and fine tune the concepts in the course of the process. DBR processes are mainly considered to be interactive, cooperative, iterative, flexible and environmentally dependent. The real importance of DBR in educational technology can be found in laying the foundations for innovation.

5. Aspects to review physics textbooks of various countries
Before writing the chapter, team members reviewed physics textbooks used abroad in details (written in English, German, Austrian, Russian, French, Italian) with a view to the following pre-defined considerations, comparing them with their counterparts used in Hungary [8-13].
Table 1: Aspects to review physics textbooks

| Question                                                                 | Answer                                                                                           |
|------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Which chapters of physics the book deals with?                         | To which extent the topics therein resemble to those in domestic course books and to which extent are they different. Does their layout follow the traditional system of physics? |
| Does the book make students work?                                      | How diverse is the writing up of a lesson (core material, parts to be learnt, exercises intended to deeper understanding of the concept, ratio of qualitative and quantitative tasks, technical applications, high-tech points of interest, connections with other sciences and humanities, how similar or how different the length of each of the lessons are, etc.) |
| Are each of the lessons structured the same way?                       | Does the book help teachers within individual lessons to differentiate in a personalised manner (in terms of formulation of the content, and of the exercises given, etc.)? |
| Does the book help teachers within individual lessons to differentiate in a personalised manner (in terms of formulation of the content, and of the exercises given, etc.)? | Presentation of phenomena in qualitative approaches, videos, measuring experiments with their results used, model experiments, simulations, etc. |
| To which extent the book relies on experimentation?                    | Does the book have background materials on the Internet for students to see? What type and how is it used? |
| To which extent the book relies on the use of computers?               | Does a CD come with the book and if yes, what is the content? |
| Does the book have background materials on the Internet for students to see? What type and how is it used? | Proprietary home page for students, electronically completed and uploaded exercise sheets, tests, referrals to websites found interesting from the perspective of the topics given to students, etc. |
| Does the book have background materials on the Internet for teachers to study? | Recommendation of background materials, methodological suggestions, electronic forum to discuss possible problems, etc. |
| Are the illustrations in the course book related strictly to the curriculum or are they diverging? | Pictures, figures, etc. |

Figure 1: One of the textbooks selected for assessment

The answers to the questions listed above were instrumental in selecting the good practices or in screening out unnecessary components and in designing the architecture of the chapter in progress. The elements assisting the process of learning and comprehension were searched for along these answers, and the fundamental information, which must be included in the core material. Contents having
significance beyond themselves but found inspirational for students intending to continue their studies are presented in supplements.

6. Text book chapter
The completed chapter is dedicated mainly to students who have already decided during their years spent in a comprehensive school to learn sciences in their further education, and want to take their G.C.S.E. (General Certificate of Secondary Education) examination in physics.

The conventional writing up was amended also in terms of the construction of the topic. Physics textbooks in high schools are putting more emphasis on wave behaviours. While discussing the different wave types, they are dealing with phenomena such as interference or reflection. Our method approaches this differently by teaching them in the topic of mechanical waves, then replacing the familiar linear structure with a more parallel one. For each wave type, one wave property is explained in each of the lessons. That is, sound, light, and electromagnetic waves in general. Instead of discussing each chapter over and over again, we are associating a wave property to each remaining wave type. Using this structure allows us to much deeper and more detailed discussions for every chapter as well as mentioning interesting facts and talking about their connection with other science subjects.

![Figure 2: The structure of the book. Types of the waves do not follow each other linearly. They are discussed parallel grouped by the wave properties](image)

Efforts were made to make the chapter short, additions, study aids, and supplements can be accessed using QR codes. Supplementary contents are diverse and available in great volumes, therefore all students can search for the contents which they are most interested in and taking the book in their hands repeatedly can view different vademecums.

The completed chapter can be found on a home page developed in conjunction with students. Core material in the lessons of the chapter was maximised in two pages. Additionally, the following supplements were included in each lesson:

- pictures, figures, phenomenon videos associated with everyday phenomena matching the theme
- background deductions for interested students
- supplement in history of physics, points of related scientific and technical interest, highlighted
- the topics suitable for teacher concentration
- sample exercises, practicing tasks
- ideas for individual experimentation, using household tools
- simulation programmes
- on-line check list with instant indication of the results (knowledge check), etc.
- videos not available to class presentation on pages designed for students
- simulations
Figure 3: Detail from the on-line curriculum

Figure 4: One of the on-line check lists (a translation from the Hungarian book)

Figure 5: Boxes in the 'Refraction' Chapter lead to additional supplements

The hard copy textbook can be completed using these aids accessible this way and fit to the curriculum with a wide range of state-of-the-art ICT tools. This way they provide the opportunity for both teacher and student to select items most appropriate to their personality, learning/teaching habits, customising and hence, making the learning process more efficient and enjoyable.
7. Results

The home page – and hence, the e-learning material – was tested in the first round with a smaller group. The experimental group has 14 members. They learn physics at an advanced level and they finished the study of the examined topic right before they filled in the test. All 47 students in the control group learn physics at an advanced level, as well, and about half of them finished learning about the topic at the same time. Others in the control group learnt about the wave theory a year earlier but they were preparing for the final exam at the time of the examination. The tests contained 12 multiple choices type questions selected from earlier tasks of (Hungarian) advanced level final exams. These test questions are designed to evaluate deep understanding. In the last year’s final exam the average result in the country was 10,4 correct answers out of 15. In our test there were questions about mechanical waves – including the sound waves – and optics. The average result of the experimental group is 10,2 and the control group’s is 9,1. (Results refer to the number of correct answers out of 12.) The difference is about 10%, which is not necessarily significant but definitely encouraging. Of course, other factors can also affect the results. The students in the experimental group are in a science-oriented class while about half of the members of the control group learns in a regular class. This can make a difference in their interests and it may influence the teaching methods and manners of their teachers. The results of both groups are above the last year’s national average because the participants learn in a reputable secondary school.

![Figure 6: Answers for the questionnaire](image)
Besides the test, we asked the students to fill in a questionnaire in which we asked them about the use of the online version of the book. In that part, we involved another experimental group. They used our experimental book but they do not learn at an advanced level. Thirteen students filled in the questionnaire; 7 of them belonging to the advanced level group and 6 students coming from the basic level group. It was the first feedback in which we mainly intended to assess how easily the homepage could be used. After some data about their school type and level of physics group, we asked which parts of the content they used and in which aspects they found useful – if at all. Answers in fig. 6 show that they used all chapters. The answers also show the composition of the respondents – six of them used the matter waves part of the book. Students clearly received the new form of learning positively. Most of them found the book useful in terms of providing a summary prior to school tests and found that it helped to clear up certain phenomena. They did not feel that it increased their motivation, however, the online contents (videos, simulations) were welcome, and the students felt that they made the topic more interesting. 9 of them answered that the book helped the learning process, 3 of them answered “partly” and 1 of them felt it did not help in the overall learning.

It was mainly intended to assess how easily the home page could be used. Minor fine-tuning, and changes were made to it based on students’ feedback. Having finalised the home page contents, our goal is to try the e-learning material to a wider audience.

8. Complement
Due to the Coronavirus, the situation of the education in Hungary has changed as of 23 March 2020. Schools closed and shifted to distance learning. Our experimental webpage [14] became a useful source. We shared it in teaching communities and we have been using it as a book for our students. We hope that it helps our colleagues as it has been helping us. Now we have an opportunity to test it widely.

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