

## Remote Sensing from Space: A Master's Level e-Learning Tool

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### *Abstract*

An e-learning online module has been devised and constructed to facilitate the teaching of *Remote Sensing of the Troposphere from Space* to research students at a Master's level. The module is stand alone, although it can be readily encompassed within a standard course management system. The module could be regarded as an interactive on-line text book, with the advantage that the exercises provide immediate feedback to the student of his or her comprehension of the high level material.

The scientific content is presented as study pages under three headings: remote sensing from space, the basics of radiation transfer, and retrieval procedures for tropospheric satellite data.

The student is encouraged to test his or her comprehension of the material through exercises on the scientific topics. There are five exercise types with further variants, and the student can improve his or her understanding of the topic as he or she progresses.

The module is intended for e-learning and not for testing. The module was tested at a feedback workshop by both students and senior colleagues, and is used by several European research groups. It is publicly available.

The paper concludes with a distillation of our experience in the development of the module, together with the lessons learned and the requirements needed to develop a successful module.

### *Keywords*

**Audience:** Graduate Education / Research

**Domain:** Environmental Chemistry, Chemical Education Research

**Pedagogy:** Computer-Based Learning

**Topics:** Atmospheric Chemistry, Spectroscopy, UV-Vis Spectroscopy,  
IR Spectroscopy, Learning Theories

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### Introduction

Using remote sensing instrumentation on-board orbiting satellites, it is now possible to obtain global information about pollutants in the troposphere and, in some cases, in the atmospheric boundary layer (1). The retrieval of such tropospheric information from the satellite data is a large and growing task requiring much expertise before it can become fully operational. There are thus a growing number of research groups involved in obtaining tropospheric data, validating and evaluating it, and using it, both to improve our understanding of the global troposphere and to study the changes under the impact of man's activities. The AT2 e-Learning Module was developed to provide an on-line introduction for new postgraduates in this area, and also to provide an on-line background for those interested in the possibilities of remote sensing of the troposphere from space.

ACCENT-TROPOSAT-2 (AT2) is an integration task of ACCENT, the EU network of excellence for atmospheric chemistry. AT2 brings together the European community of researchers in the field of satellite remote sensing of the troposphere to address the need for global information about trace atmospheric constituents. Its aim is to facilitate the generation of tropospheric data products, to encourage their use for research in the medium term, and to indicate their potential use in the development of environmental policy (2).

One of the tasks the AT2 group set itself was to develop the remote sensing module described here, as part of the ACCENT Training and Education (T&E) activities (3). The AT2 e-learning module could be termed an 'interactive textbook': it presents the subject material to the student and, by means of interactive exercises, allows the student to check and to improve his or her comprehension of this material. It is designed to complement the traditional text book and other learning material.

The educational aim of the module is to communicate an understanding of the role of NO<sub>2</sub> in atmospheric chemistry (4) as well as the retrieval and use of NO<sub>2</sub> observations from space (5, 6, 7). NO<sub>2</sub> was chosen because: a) it is an important natural trace substance and a man-made pollutant; b) it can be readily detected in satellite spectra; and c) it exists in the stratosphere and the troposphere. Thus all the important retrieval steps including stratosphere/troposphere separation can be demonstrated.

The module is intended for use by students at a Masters level, and thus a graduate level background in science is assumed. However, students often come from different disciplines (physics, chemistry and earth sciences and mathematics, for example), and so the module is intended to familiarize these new graduate students with the basic science of a complex field.

The module itself has been successfully tested in a workshop and in research groups throughout Europe. It is now available on line.

The module fits well within the current thinking about "learning objects", since it is a knowledge-based object that is "discoverable, modular and interoperable", or in another definition, "self-contained and re-usable" (8)

We gained a great deal of experience in the development of the module, so it seemed worthwhile to communicate in this paper the lessons learned and to indicate the requirements needed to develop a successful module. Some of the pitfalls to avoid are also pointed out. These fit with the known demand for advice about "effective time-efficient" ways of using modern aids to support student learning in higher education (9).

### **Presenting the material in the module**

The approach used in the module includes two didactical aspects (10): presentation of information and education by training, and encouraging the students themselves to test and improve their own understanding of the material.

In terms of presentation, the module introduces the student to the topic using a step-by-step introduction to the use of satellite observations to calculate NO<sub>2</sub> distributions in the troposphere. It shows how the results are derived from a real data set of raw data observed by the satellite-borne instrument, and how they are interpreted. In addition, it offers references and links for further reading.

### **Accessibility**

From the system point of view, the aim of the project was to develop an e-learning module with a high level of interactivity that could operate as a stand-alone module. The module is designed to run in a modern web browser. It consists of normal web components – HTML files, JavaScript scripts and cascading style sheet files. Unlike many other proprietary e-learning systems, it does not use plug-ins or require special code or languages. It requires no server-side 'delivery' techniques, and can be delivered from a web-server or accessed by a network client from a file-server. It is thus stand alone and can be stored on a CD-ROM or USB memory stick and used off line. Being stand alone, it can also be integrated seamlessly into any of the major course management systems such as MOODLE or WEB-CT without appreciable additional effort. As a stand-alone system using normal web components, it is future-safe and completely portable.

The AT2 module was created using the LexEOS E-learning system (11), which stores its data in the form of XML files that are editable using a normal XML editor. The XML source files are freely available to authors and can be created and edited at will.

### **Presenting the scientific content**

Construction of the module falls into two parts – *study pages* to present the scientific content, and *exercises pages*, with which, the student can test his or her knowledge.

The initial scientific content was delivered as a set of PowerPoint lecture slides, which were modified and augmented as the module developed. The initial task was, for each slide employed, to write a description which is a demanding exercise in itself; as common experience shows, some lecture slides need only a short description, while others may require a considerable time to present.

The scientific content is divided into three parts: Remote Sensing, Basics of Atmospheric Radiation Transfer, and Retrieval Procedures (see Figure 1). This section can best be appreciated if read with the module in view:

<http://www.iup.uni-bremen.de/deu/lehre/toelearning.html>

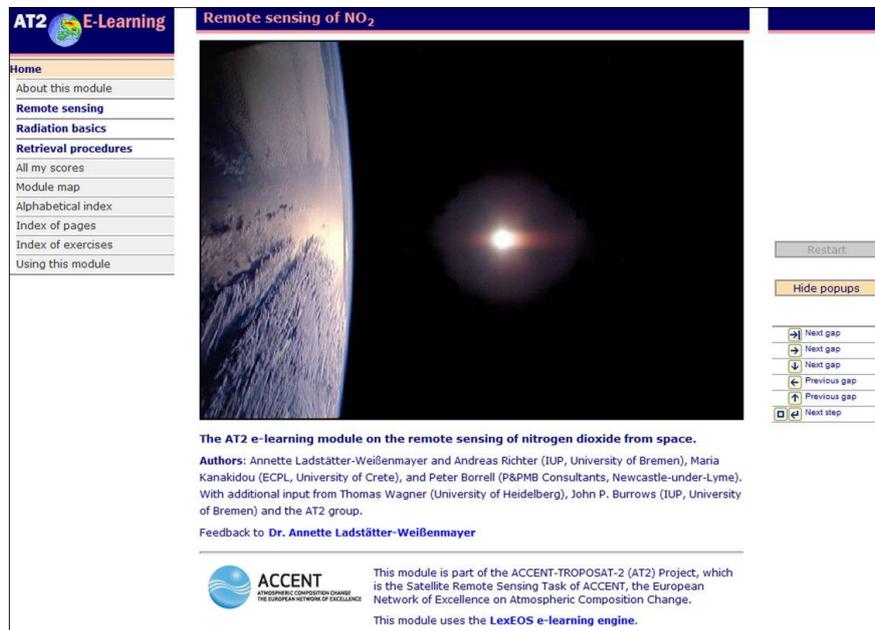


Figure 1. Starting the AT2 e-learning module on "Remote Sensing of the Troposphere from Space", you will find three segments in the browser window:

- Left column: index and your current position in the module
- Middle: main text and tutorial questions
- Right column: navigation (only within the same level), some options and exercise scores

The first chapter, on Remote Sensing, deals with the importance of the nitrogen oxides,  $\text{NO}_x$  (=  $\text{NO}$  and  $\text{NO}_2$ ), and the use of satellite measurements in general. Different types of nitrogen compounds in the atmosphere, sources and sinks and their altitude and spatial distribution are explained in more detail (4) The reactions of stratospheric as well as tropospheric  $\text{NO}_2$  are described using overviews, chemical equations and explanatory text. Since the tropospheric  $\text{NO}_2$  is highly variable in space and time, the advantages of remote sensing from space are evident.

As an example, the student is taken, step-by-step, through a case study of biomass burning. It is presented in terms of the emission and distribution of the trace gases,  $\text{NO}_2$ , formaldehyde,  $\text{HCHO}$ , and ozone,  $\text{O}_3$ , which are observed with the GOME satellite instrument (see Figure 2) (12, 13).

Figure 2. Biomass burning; a case study.

The first section of the module describes the satellite instruments, GOME (14) and SCIAMACHY (15, 16), from which many of the current tropospheric measurements are made. GOME was launched in 1995 on satellite ERS-2 in a sun-synchronous near polar orbit at a mean altitude of 795 km. It measures the sunlight back-scattered from Earth's atmosphere and/or reflected by the surface at wavelengths between 240 and 790 nm with a spectral resolution of 0.2–0.4 nm. SCIAMACHY, a more elaborate instrument, was launched in 2002 with a primary mission to perform global measurements of trace gases in the troposphere and stratosphere. The solar radiation transmitted, backscattered and reflected from the atmosphere is recorded at a better spatial resolution over the range 240 nm to 1700 nm with a spectral resolution of 0.2 nm to 1.5 nm, and in selected regions between 2000 nm and 2400 nm. SCIAMACHY has three different viewing geometries: nadir, limb, and sun/moon occultation which yield total column values as well as distribution profiles in the stratosphere and (in some cases) the troposphere for trace gases and aerosols (15, 16).

The module explains satellite scanning concepts and techniques such as polar, near-polar and sun-synchronous orbits, swath, wavelength ranges, scan sequences, different observing modes such as nadir, limb and occultation mode and their measurement sequence (see Figure 3) (16).

The screenshot shows an e-learning interface for 'Remote sensing of NO<sub>2</sub>'. The main content area is titled '1.2.1.2 Sun-synchronous orbits'. It contains two diagrams: 'Polar orbit' and 'Sun-synchronous orbit'. Below these is a caption: 'Fig 1.2.1.2.1: Polar orbits and sun-synchronous near-polar orbits during the Earth's year. Image: AT2-ELS'. The text explains that in a near-polar orbit, the asymmetric gravitational pull of the Earth causes the orbit to precess at almost exactly the same rate that the Earth orbits around the Sun (approximately one degree per day), in turn causing the orbital plane to appear fixed with respect to the sun, or to be sun-synchronous. It also notes that orbits that precess are also known as retrograde orbits. Below this is another caption: 'Fig 1.2.1.2.2: The ENVISAT orbit at 100 min intervals Image: AT2-ELS'. The text explains that the constant angle of the orbital plane to the Sun results in a constant equatorial crossing time, which is important for remote sensing from space because the Sun is nearly at the same position whatever the current longitude of the orbital position. This is important for the subtraction of stratospheric components during data retrieval. The interface also features a sidebar with navigation options like 'Home', 'Remote sensing', 'Importance of NOx', 'Satellite measurements', 'Techniques', 'Orbits', 'Sun-synchronous orbits', 'Swath', 'Exercise', 'Wavelength ranges', 'Satellite instruments', 'Radiation basics', and 'Retrieval procedures'. There are also buttons for 'Previous', 'Next', 'Menu', 'Restart', and 'Hide popups'.

Figure 3. Polar orbits and sun-synchronous near-polar orbits during the Earth's year.

The second section, on the basics of atmospheric radiation transfer, deals with the question "How do we use satellite measurements to determine tropospheric NO<sub>2</sub> columns?" To answer this question and to understand the background of the retrieval procedures of satellite-based data, an introduction to the concepts of electromagnetic radiation, radiative transfer and the radiation transfer equation are given. Wavelength, radiance, and irradiance are defined, as well as the general terms and units commonly used in this field. Blackbody radiation, blackbody absorption and Planck's Law are explained in more detail.

To understand the radiative transfer in the atmosphere, different processes such as absorption, scattering and reflection have to be taken into account. The Beer-Lambert Law is introduced together with Rayleigh and Mie scattering processes (events, after which the scattered photons have the same wavelength but not the same direction as the original photon), together with Raman scattering (a scattering event, after which the photons change their wavelength). The solar radiation reaching the Earth's surface is partly redirected back into the atmosphere by reflection, which depends on the surface albedo (reflectance), which in turn depends on the characteristics of the surface. Thus the light finally reaching the spectrometer is determined by the radiative transfer of sunlight that falls on the Earth and is multiply scattered in the atmosphere.

The third section on Retrieval Procedures explains the intricate process of data retrieval. Trace gases such as NO<sub>2</sub> are detected by their absorption spectra and the concentration is determined by DOAS (Differential Optical Absorption Spectroscopy). The DOAS method (17) is explained both graphically in a step-by-step guide and, mathematically, in a step-by-step presentation of the DOAS radiative transfer equation. The student is shown the way that the earthshine spectrum for each ground pixel is compared to the solar irradiance at the satellite and how a value for the concentration of NO<sub>2</sub> in the tropospheric column above that ground pixel is derived.

The whole process of analyzing the total vertical column, extracting the stratospheric part and finally retrieving the tropospheric vertical column amount, is explained with a sequence of retrieval steps that takes the student through the complete retrieval process.

Initial analysis of the data yields a so-called slant column density of  $\text{NO}_2$ . This must then be converted to the required vertical column density by use of the air mass factor (AMF) which is based on radiative transfer calculations (18, 19). Some important influences such as the geometry, altitude, albedo and wavelength are explained and illustrated by diagrams.

Two common methods of eliminating the stratospheric column density from the total amount to yield the final tropospheric column densities are described: the reference sector method and the limb mode profile approach, together with their respective advantages and disadvantages (6, 20).

An example of the final outcome of such an analysis is shown in Figure 4. It can readily be seen that the concentrations of the air pollutant  $\text{NO}_2$  over China has increased in the period between the two sets of observations, while it remained the same over other regions such as Japan.

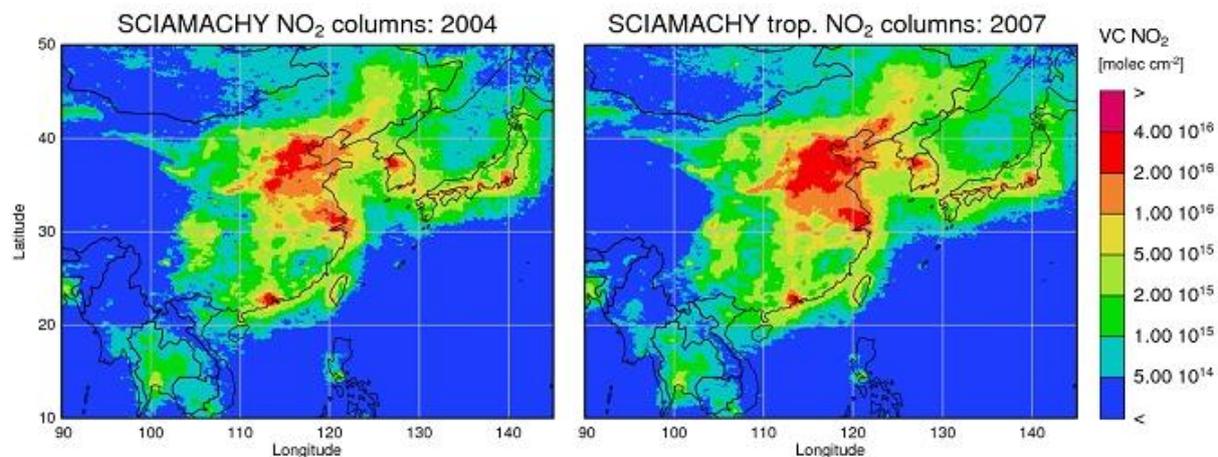


Figure 4. Distributions of  $\text{NO}_2$  over China in 2004 and 2007, constructed from observations with the SCIAMACHY instrument. For a more detailed study see Richter *et al.*, 2005.

It should be noted that, as a teaching tool, the module itself does not provide access to real time data, only to one selected example. Real time data is available from different sources on the web and links to these data sources are included in the module.

### Testing comprehension in the module

In order to verify the level of comprehension attained, the learning process is supported by about 70 interactive exercises that allow the student to evaluate his or her understanding and comprehension of the material at each step. Given the advanced level of study at which the module was aimed, these exercises encompass conceptual as well as factual material. The present section gives a guide to the structure and to the scientific content to illustrate the level of the work and to indicate how the module was constructed.

The potential advantage of e-learning over a text is that the student can be given the opportunity to test their own comprehension as they work their way through (9). Although the interactive exercises in the module test the student's understanding and knowledge, they are not designed to be tests in the traditional sense. Students can repeat exercises as often as they wish and so improve their scores and understanding.

## Evaluation and correction of the students' work

A number of different exercise types are used in the module and they all use a standard procedure for the evaluation and correction of the students' work. At any time when working in an exercise – whether all questions have been answered or not – the student can choose to evaluate his or her answers. Correct answers are marked in green, incorrect answers in red. When there are incorrect answers in the exercise the student can choose to try again and is able to modify the incorrect answers. Answers that are correct only after the first attempt are marked in a pale green. There are usually only a limited number of attempts available. If the number of attempts is used up and there are still incorrect answers in the exercise, the correct answers are substituted, marked in blue.

So an important principle of the module functionality is that, upon completion of an exercise, the student is only left with correct answers on the screen.

## Exercise types

Five exercise types are used in the interactive sections of the AT2 e-learning module.

Gap option exercises	Each gap to be filled can cycle through several alternatives of text or diagrams.
Category marker exercises	A table of alternatives is provided which must be fitted to the several gaps in a text, say.
Multiple choice exercises	One or more questions or statements together with the associated options are presented. The options are in effect, interactive gaps that can be selected and deselected.
Gap-fill exercises	Contains a number of gaps and a table of items that can be put in the gaps. Items and gaps can be in any ratio.
Type-in exercises	The gaps display placeholders and the student has to select and type into each gap (good for chemical formulae <i>etc.</i> )
Annotated text	Contains a number of gaps, acting as annotation hot-spots and not requiring input from the user. Clicking on the gaps displays an associated annotation.

Each of these principal types has several variants. A common feature of these exercises is the use of "gaps" that require some input from the user as an answer. Gaps need not only be text elements, but can be texts within images, images within texts or images within images. Structurally, they can be incorporated into run-on text or organized in some way such as in tables or within mathematical expressions.

The student can fill the gaps using either mouse or keyboard at will, which makes the system more accessible for people with disabilities.

A detailed description of the exercise types is given in the on-line supplementary material to this paper.

## Scoring the tests

Although the students can improve their scores, many like to have a record of their work. The module therefore offers a complete scoring system with the following features (see Figure 5):

- scoring in the control panel, which is carried during the work;

- score tables which list the scores achieved in a group of exercises; each exercise is listed together with the number of correct, 'half-correct' (answers only correct after the first attempt) and incorrect answers it contains.
- saving and printing scores; scores are saved whenever the module is closed or refreshed.

The screenshot shows the AT2 E-Learning interface. On the left is a navigation menu with options like Home, About this module, Remote sensing, Importance of NOx, Satellite measurements, Satellite instruments, Radiation basics, and Retrieval procedures. The main content area is titled 'Remote sensing of NO<sub>2</sub>' and includes a section '1 Remote sensing procedures' with introductory text and three bullet points: 'The importance of NO<sub>x</sub>', 'The techniques of satellite measurements', and 'The characteristics of the satellite-borne instruments'. Below this is a 'Score summary' table for 'Remote sensing' exercises. The table has columns for Exercise, Correct 1, Correct 2, Incorrect, Questions, Percent, and Attempts. A summary row at the bottom states: 'You have done 9 exercises in this section, for which your total score is 33%'. On the right side of the interface, there are buttons for 'Restart', 'Hide popups', and a set of navigation arrows for 'Next gap', 'Previous gap', and 'Next step'.

Exercise	Correct 1	Correct 2	Incorrect	Questions	Percent	Attempts
1 Exercise	2	0	8	10	20%	2
2 Exercise 1	3	0	5	8	38%	2
3 Exercise 2	4	1	2	7	71%	2
4 Exercise	0	0	4	4	0%	2
5 Exercise	1	0	5	6	17%	2
6 Exercise 1	0	0	6	6	0%	2
7 Exercise 2	4	1	3	8	63%	2
8 Exercise	2	4	1	7	86%	2
9 Exercise 1	0	0	6	6	0%	2
10 Exercise 2	0	0	0	0	0%	0
11 Exercise	0	0	0	0	0%	0
12 Exercise	0	0	0	0	0%	0
13 Exercise	0	0	0	0	0%	0
14 Exercise	0	0	0	0	0%	0
15 Exercise	0	0	0	0	0%	0
16 Exercise	0	0	0	0	0%	0
17 Exercise	0	0	0	0	0%	0
18 Exercise	0	0	0	0	0%	0

Figure 5. A summary of scores obtained working with a group of exercises.

### Help systems

While the interface has been designed to be as intuitive as possible, a large range of context-related help is available. Exercises can offer help on their functionality with features such as:

- pop-up windows containing a guide for using the particular exercise type;
- information about particular functionalities – entering mathematical expressions, for example;
- content tips for the completion of the exercise;
- pop-up 'tooltips' when the cursor is over that element.
- glossary definitions.

Most of these features can be deactivated or re-activated at will.

### Course management environment

The purpose of the AT2 module is to provide a variety of laboratories in different institutions in different countries with a course on remote sensing from space using real data from the satellites GOME and SCIAMACHY. Therefore it was best to have a stand alone module with no association with a particular course management system.

However it has been constructed so that it can be fitted into MOODLE and other, commercial, course management systems such as Blackboard and WebCT. We used an implementation within MOODLE at our feedback workshop in order to collect opinions from the students and others testing the module.

One could, in principle, integrate the module into a course management system to allow assessment of students, but this defeats the philosophy of our approach which is to encourage students to achieve comprehension of material at an advanced level. It might however provide a useful check on whether a student has actually addressed the material.

## **Evaluation of the Module**

As part of the development, the module was tested in a class room environment at a workshop held in Heraklion, Crete in June 2006. The "students" were about 30 colleagues, some senior, some postdoctoral, and some, research students. Feedback was obtained with comments collected *via* the MOODLE environment in which the module was installed on that occasion. While there were many suggestions for improvement, most of which have been implemented, the overall reaction appeared to be very favorable. The module is now being used in teaching at the University of Bremen and for additional study in Crete and Heidelberg.

## **Lessons learned**

In the extensive discussions that led to the module, in its development and in the feedback obtained, we gained some useful insights which are worth rehearsing, particularly in view of the known demand for advice about "effective time-efficient" ways of using modern aids to support student learning in higher education (9). The insights are as follows.

a. E-Learning requires a different approach from both teacher and student if any added value is to be achieved from the interaction with a PC. With the work required, it is helpful if the teacher is part of a production team. The student is far from passive and requires a high degree of motivation.

b. While a PC offers the possibility of numerous additional effects in presentation, the aim is to produce an educational module rather than a 'sound and light' show! It is easy to spend a large proportion of one's resources on clever effects, without pausing to wonder whether they actually add much to the task in hand.

c. A module offers many possibilities for cross-linking and internal referencing. But these too can be distracting. The number of cross links should be kept small, if people are to maintain a focus and a coherent thread.

d. Similarly, the internet offers endless possibilities for additional material. But, again, the number of external links should be kept to a minimum if the student is to focus on the matter in question. Caution is needed when encouraging students to learn in a "Media Rich" environment (21).

e. The module should be largely self-contained in teaching material.

A final point is updating or correcting the material and exercises. It was advantageous that a system of normal html pages *etc.* from an xml source were developed. We are thus able to correct errors and misunderstandings. However the future safety is less clear, and this will apply to the development of any e-learning system with any sophistication.

## Conclusions

The AT2 e-learning module on "Remote Sensing of the Troposphere from Space" has been devised and constructed to facilitate the teaching of the *Remote Sensing of the Troposphere from Space* to research students at a Master's level.

The module could be regarded as an on-line text book, but it has substantial advantages. It provides a straightforward and interesting start to a complex subject while still providing in-depth information on the topics. The animations, such as those for the retrieval processes or scanning sequences of a satellite, are much more instructive than would be possible with a textbook. The integrated interactive exercises and reviews offer direct and immediate feedback to the student about his or her understanding and comprehension of the material being studied.

However we would emphasise that e-learning in this form is not intended to replace written material, but to take its place alongside traditional textbooks, lectures and tutorials.

A further important point is the open access to the module. Students with internet access from all over the world can log-in and use it to gain knowledge on the topic at the level in which they are interested. Such an approach spreads knowledge globally and also helps to encourage aspiring academics in the developing world to consider this promising field.

In summary:

- a. The module presents high-level material and allows students to test and obtain immediate feedback to improve their comprehension.
- b. The scientific content is presented as a series of nearly a hundred illustrated and annotated study pages.
- c. Comprehension is tested by means of five different exercise types with a number of variants.
- d. The student can score his or her own performance.
- e. The module is intended as an *e-learning* system, rather than a testing system.
- f. The module attempts to lead the student through the processes of assimilation
- g. The system is readily accessible on line.
- h. The module uses standard html and runs in an internet browser.
- i. The module can be run from a web server, a file system or from portable media such as a CD-ROM or memory stick.
- j. The module is stand alone and accessible from the internet

<http://www.iup.uni-bremen.de/deu/lehre/toelearning.html>

However it can be implemented within most course management systems.

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