Proceedings of 20th International Congress on Acoustics, ICA 2010

23–27 August 2010, Sydney, Australia

Problem Based Learning in Acoustics at Aalborg University

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PACS: 43.10.Sv

ABSTRACT

The master program in Acoustics (M. Sc.) from Aalborg University is taught at the Department of Electronic Systems. The M. Sc. program consists of three semesters with course units and problem based project work organized in groups, and a final semester for a master thesis. During the first three semesters, the learning objectives are distributed between courses with independent examination, and a semester project. Each semester has a theme the projects must comply with. Either supervisors, students or industry propose the problem that become the basis for the project work. Under supervision, the students narrow down the problem, address possible solutions, and typically implement one or more of the options for further evaluation. The courses supplement the project work by adding specific and general knowledge of the subject areas of each semester. The courses either have direct application in the project work, or are defining for the candidate's professional profile. This presentation gives an overview of Problem Based Learning organized in groups in the M. Sc. in Acoustics program of Aalborg University. Examples of projects and course activities are presented to illustrate the relation and interaction between course and project work.

PROBLEM BASED LEARNING AND THE AALBORG MODEL

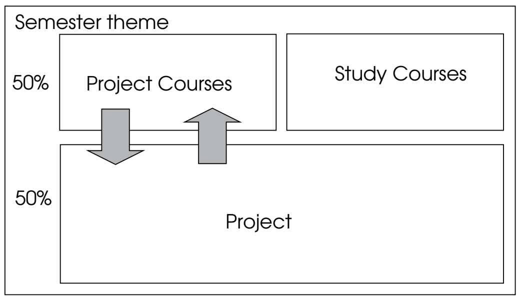
In higher education there is a constant need for being up-to-date with the latest scientific knowledge and professional practices, in order to promote qualified candidates required by modern society. This is a great endeavor that challenges the structure and basis of the educational institution. In order to adapt to the fast changing requirements of society and industry, innovative educational methods are required, Problem Based Learning (PBL) is such a method.

PBL is based on a dynamic relationship between professional practice, scientific research and education (Kjaersdam and Enemark 1994), in which the motivating factors are real-life problems present in scientific research, industry and/or society. The main idea is that scientific knowledge, learning objectives and competences are continuously being evaluated and renewed through the pursuit of current relevant problems.

In Aalborg University PBL has been organized as project work, where each semester a group from 4 to 6 students carry out a major project. In addition to the project the students participate in courses, that are either of direct relevance to the project, or of more general character specific to the chosen specialization. Figure 1 shows the structure of a semester in what is called the Aalborg PBL Model (Kolmos et al. 2006).

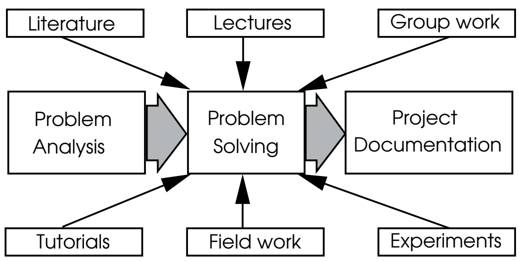
Within a semester, the students are involved in several different complementary learning situations, lectures, tutorials, experiments, group work, seminars, individual study, etc. The combination of these activities leads to in-depth theoretical and practical knowledge related to a given problem area, starting from the specification of a problem to the documentation of a given solution, this is shown in Figure 2.

Through Project-organized problem-based learning (POPBL) in groups, the students develop competences in the areas of project



Source: Kolmos et al. (2006)

Figure 1: Semester structure of the traditional Aalborg PBL model. The project and courses are developed within a semester theme, which sets the frame for the competences developed throughout the semester.



Source: Kjaersdam and Enemark (1994)

Figure 2: Problem solving process in a PBL semester project.

management and organization, together with verbal and written communication skills. Additionally, within the groups, there is a great deal of peer learning, in which students share their skills to achieve a common goal. Another important element of the group work is the social environment generated. The students belong to a *unit*, and as such have responsibilities to it. The groups set their own working routines and contact with supervisors is made to the unit and not to individual students. At the Master level, there is a great number of non-danish students, making an international working environment that forces the students to confront social and cultural differences common in modern work environments.

POPBL can be characterized by student centered learning in a collaborative and interdisciplinary environment that motivates high level thinking. Students develop skills in problem solving, communication, cooperation, negotiation and decision making.

Through POPBL the goal is to go from knowledge of literature to the necessary knowledge to solve a problems; from understanding common knowledge to the ability to develop new knowledge, that is, *to learn how to learn*.

MASTER OF SCIENCE IN ACOUSTICS AT AALBORG UNIVERSITY

For several years an M.Sc. program in Acoustics has been offered at Aalborg University. The program is conducted in English. Throughout the years an almost equal representation of internal students from the bachelor specialization in signal processing, and foreign students with a similar background have followed the program.

The structure of the program has been defined according to a wish of providing acoustical engineers with a background sufficiently broad to match the potential job profiles in e.g. loudspeaker production, hearing aid manufacturing, acoustic consultancy, transducer manufacturing, Hi-Fi, broadcast (technical part), pro-audio, measurement equipment, academia etc.

The program is research based, and it gives the students a broad introduction to acoustics within the topics of signal processing, physical acoustics, room and building acoustics, electro-acoustics, psychoacoustics, measurement technique and acoustic noise.

The main objectives of the program are to:

- acquaint the student with theories and methods related to the use of advanced digital signal processing on signals of acoustic origin.
- provide the student with understanding of basic acoustical measurement principles and acquaint the student with the use of acoustical transducers.
- provide the student with broad background knowledge of acoustics, hearing and audio engineering.
- To acquaint the student with scientific methods in acoustics.

The program is running in accordance with the model of POPBL as explained in the previous section.

Semesters of the Acoustics Program

The study is sub-divided into four half-year thematic semesters, each including a course activity of 7-8 ECTS and 22-23 ECTS (European Commision) problem-based project work. Approximately half of the courses have written or oral pass-fail exams (Study courses). To facilitate the projects, a supervisor is appointed to each, and a number of project unit courses with close relation to the project themes are given. These courses (Project courses) are assessed in conjunction with the project exams with individual grades (see Figure 1).

The content of the 4 projects are guided through semester theme descriptions laying out the framework within which the specific project proposals made by supervisors or students are expressed.

First semester

The first semester is divided into two parallel tracks:

1. One followed by students that have a bachelor education from Aalborg University with a profile directly matching the admission requirements. These students have worked with the POPBL model throughout their bachelor study.
2. One followed by students from the international intake. This track is targeted a leveling of different competencies – especially introducing POPBL.

The leveling of competencies for students from other institutions is partly done through the course *Introduction to POPBL*. The course targets facilitation of the students' ability to study in an environment with focus on PBL through team work, often in multicultural teams or groups. The focus of the course is on:

- POPBL in general
- Planning and documentation of a project
- Group work:
  - roles within a group
  - conflicts – and how to solve them
- Intercultural competencies
- Learning styles

These topics are presented in the course both in the form of lectures and group exercises, where small scale projects are done by the groups within the course.

The first semester is focused on stochastic signal processing on sound signals. The students gain experience with system identification and signal models, and the emphasis is on audio signal processing. Courses in this semester cover areas of: *Stochastic processes*, *Statistical signal processing*, and for track 2 *Introduction to POPBL*.

Projects in this semester has been e.g.: Audio effect processing, automated recognition of drum types, computer based audiometer, piano transcription based on wavelet decomposition and neural networks.

Second semester

The second semester – as the first – has its focus on digital signal processing applied to acoustical signals, but with a significant emphasis on the understanding of the physical processes around sound and acoustics. The aim is to build up competencies on the physics of acoustics, and to provide a basic understanding of typical sound fields and their properties. To make a connection between the physical and mathematical domain (signal processing) a part of the curriculum is focused on how to measure and analyze sound, by the understanding and use of acoustical transducers and digital audio techniques.

The project work is based on an acoustical problem, which is analyzed and solution strategies developed. The project work includes measurements on acoustic signals, signal analysis and digital signal processing. The solution strategies are evaluated and compared, possibly by computer simulations. The chosen solution is implemented, e.g. by using a computer or dedicated electronic equipment. Examples of projects are: Digital optimization of loudspeakers, digital control of loudspeaker directivity and active noise reduction.

On the second semester, courses are given in the areas of physical acoustics, electro acoustics and signal processing. (*Funda-*

mentals of acoustics, *Acoustical transducers*, *Acoustical measurement technique*, *Adaptive filters*, *Inverse filtering and deconvolution*).

Third semester

The theme of the third semester is *Acoustics and sound perception*. It is targeted the achievement of a broad background knowledge within acoustics, hearing and audio engineering. The project work must reveal ability to attack acoustic problems with valid and appropriate scientific methods. Within the general field of acoustics, human sound perception plays an important role. Therefore, emphasis in this semester project has been put on fundamental principles of the human sound perception, and the psychophysical methods that combine knowledge of the physical event (the stimuli) with knowledge required for subjective evaluation of sound.

A problem with elements of physical, technical and psychoacoustics is chosen. The problem is analyzed in depth and a solution strategy is chosen and implemented. The projects shall include elements of:

- Psycho-acoustics (sound perception by human beings). New knowledge within the field of psycho acoustics is gained by planning and performing scientific listening experiments, using appropriate psychometric methods.

Additionally the project has to include one or more of the following topics:

- Electro acoustics including transducers as well as analogue and digital circuits and software for recording, processing and reproduction of sound signals. Auralization and virtual reality sound systems.
- Physical acoustics, including calculations and measurements of sound as a physical phenomenon, e.g. sound propagation in rooms and outdoors, noise attenuation, sound insulation as well as special applications of sound waves.

Projects on the third semester have been e.g.: Determination of minimum audible angle, real ear measurements for hearing aid fitting, objective measures of annoyance of sound, hearing threshold for complex low-frequency sounds, binaural sound presented through loudspeakers, surround sound over headphones with use of binaural technique.

The courses of this semester are all within the general area of acoustics and sound perception (*Architectural acoustics*, *Acoustic noise*, *Audio engineering*, *Spatial hearing and 3D sound technology*, *Human sound perception*, *Psychometry and design of experiments*).

Master thesis

The fourth semester is assigned completely to the master thesis work and no courses are given. During the semester the students work either alone or in groups of maximum 3 students. Master thesis projects cover a wide range of topics and are often closely connected to on going research areas within the Acoustics section and to proposals from industry.

Master thesis projects have been e.g.: Acoustic imaging of large structures at low frequencies; Advanced loudspeaker modeling and crossover network optimization; Analysis and improvement of the acoustic conditions during ambulance transports; Auditory filters at low frequencies: ERB and filter shape; Temporary changes in hearing of pop-rock musicians: before and after rehearsal.

Supporting facilities

As direct support for the daily project and course work, all project groups are allocated group rooms with a size of approximately 3 m^2 per student. All group rooms are equipped with standard office chairs and desks, blackboards, pin boards and network connections to facilitate the daily work. The group rooms are allocated to only one group of students at a time, and the doors are equipped with locks. For insurance reasons door keys are handed out only to the relevant group members, building officers and cleaning personnel. By these means, the group room can in fact function as the home base of a student group throughout a semester of study.

To support the experimental work, students are allowed access to state of the art laboratories and electro-acoustic equipment. The laboratories include: Two anechoic rooms, two standard listening rooms (one for multi channel setups), an audiometric room, a virtual reality room with head tracking equipment, listening cabins, reverberation room and low-frequency and infra sound facilities. All rooms are designed and equipped so that listening experiments can be carried out. There are control rooms for the setup of equipment, possibility for visual monitoring, intercom, computer connections (e.g. for the acquisition of responses), climate control in all measurement rooms, and a relaxation area for test subjects.

Admission Requirements

Every student that applies for our master program in Acoustics must have a Bachelor degree in Electrical Engineering or an equivalent level, and each applicant is assessed for their educational level as well as their linguistic level in English, as all education and communication is in English. The Danish students will normally have the last semester in their bachelor program with a specialization in analog and especially digital signal processing.

PBL IN ACOUSTICS

PBL is implemented at different levels in the M. Sc. in Acoustics, at a semester level, including the projects and related teaching activities, as well as at individual courses.

This section describes projects developed at M. Sc. in Acoustics as well specific examples of PBL used in course activities and the interaction between project and course activities.

Case 1: Sound Quality Perception of Concert Halls

This project was inspired by the well-known debate about room acoustic parameters and the optimal acoustical characteristics of rooms for sound. The problem was to find a relation if any between the objective acoustical parameters of a room, and their subjective impression on listeners.

This particular project was done in the autumn semester 2004 by six students (Antoni et al. 2004). They describe the project in their abstract as:

> The goal of this project is to find relationships between the subjective preference of a concert hall and objective parameters (instrumentally measured) and subjective parameters (judged by human subjects) which are used to describe a concert hall. The underlying theory of human sound perception, room acoustics and binaural technology is investigated. The different objective and subjective parameters used are then described. The objective parameters are: Reverberation Time, Early Decay Time, Clarity Index, Initial Time Delay Gap, Lateral Energy Fraction and Inter Aural Cross-Correlation. The subjective parameters are: reverberance, envelopment, clarity and intimacy. Measurements made in four different concert halls in Aalborg are presented. A listening experiment

> designed to collect the subjective impressions of the halls is carried out. The data gathered are finally analyzed through statistical methods. The results show that the preference is neither linearly related to the subjective nor to the objective parameters used. However some objective parameters are strongly related to some subjective parameters.

The project start by analyzing the rooms for music and the complicated relation that exists between listeners preference and the acoustics of the room. This leads to a literature review of relevant human sound perception topics, such as masking, localization, pitch perception and loudness. These issues are then to some extent related to auditory effects experienced while listening to sounds in a room, i.e. the influence of reflections and the perception of distance. The literature review continues with an overview of objective and subjective room acoustical parameters found in literature. The elaboration of this literature review was supported by the study courses in *Human sound perception* and *Architectural Acoustics*.

From this point the project deals with obtaining the necessary tools to make the comparison between listener impression and objective room acoustical parameter. Binaural room impulse responses and room acoustic parameters were measured in four different concert halls around the city. This is supported by courses in the current and earlier semesters: *Acoustical measurement technique* and *Audio engineering*. A listening test is designed for the subjective evaluation of the acoustics of each room. The stimuli for the experiment is prepared by convolving anechoic recordings with the binaural room impulse responses. Reproduction of the stimuli is done using binaural techniques, this is supported by the course *Spatial hearing and 3D audio technology*. The listening test was designed as a pair comparison test in which the same anechoic sound was convolved with different binaural room impulse responses for comparison in pairs. In this manner it was possible to evaluate the different psycho-acoustical parameters of the different rooms relative to each other. The listening test programmed in MATLAB, so the computer running the test would control the playback of sounds and the data collection. The data collected in the experiment was analyzed through statistical methods and correlation coefficients for the relation between the objective and subjective parameters, as well as the relation between the objective parameters and subjective preference were calculated. This part of the project was supported by the course in *Psychometry and design of experiments*.

The project was documented in a 126 page project report with an accompanying CD-ROM including sound stimuli, room impulse responses, data from the listening experiment, and the source code used through out the project.

Case 2: Surround sound through headphones

This is a project that has been proposed and run in several different versions. It originates in the widespread appearance of home cinema systems with surround sound. The initiating problem has been stated as the situation where consumers would like to bring their DVD movies on the go in e.g. laptop computers where a multi channel loudspeaker setup is out of reach as e.g. when traveling by train.

This specific project was made in the autumn semester 2002 by a group of five students (Barré et al. 2002). They describe the project in an abstract as:

> Based on an analysis of surround sound technology and human sound localization, this project presents an algorithm to simulate the sound reproduction of a Dolby Digital audio track in headphones. Processing methods using binaural synthesis and room acoustic properties are developed, with the purpose of creating five virtual sound sources in headphones resembling the five loudspeakers of the standard surround sound setup. A listening test has been carried out to evaluate the performance of the system. This was divided into different phases, each with a different aim. A comparison of the localization obtained with the virtual sources in headphones was performed. Furthermore, a subjective evaluation of the sound quality of a number of DVD audio tracks (accompanied with picture) using different filters in the algorithm was done.

They start by analyzing the evolution of surround sound systems, and advantages as well as disadvantages of using headphones for sound reproduction. Based on ITU recommendations they put up guidelines for an optimal surround sound system. They have a starting point for this in the courses *Audio Engineering* and *Spatial hearing and 3D sound technology*. Then they proceed – based on the same area of knowledge – with an analysis of human spatial sound perception in general as well as in connection with surround sound systems and makes a connection to a possible implementation with binaural technology, also with a starting point in the mentioned courses.

The problem analysis is terminated by the design specification of an algorithm for surround sound reproduction in headphones via the use of binaural technology.

After this they made an implementation of the algorithms in MATLAB. This involved design of the signal processing part, using their knowledge in that area, as well as establishing a real-life setup in which filters for the signal processing application was measured. The basis for this work was both the third semester courses on Audio Engineering as well as second semester courses on digital audio, acoustical measurement technique and transducers. When handling the playback over headphones, theories on equalization and deconvolution also applied.

Upon implementation of the algorithms, they did the mentioned listening tests on a group of 18 test subjects on which they first made an audiometric screening. Different instances of the algorithms and filters were put to test in order to find an optimal set of parameters for future real-time implementations of the algorithm (filter length and room influence). The tests involved psychophysical experiments with both localization and overall sound quality assessment with a real-life surround sound setup as reference (Figure 3 shows the set-up for the listening test). Based on statistical tests of significance (ANOVA) on the psychophysical data they made a conclusion on the optimum choice of parameters.

Source: Barré et al. (2002)

Figure 3: Set-up for the listening test, comparing real life localization (loudspeakers) and binaural auralization (headphones). Curtain removed for illustration purposes.

The project was documented in a 125 page project report with an accompanying CD-ROM including processed movie clips and source code.

Case 3: Audio Effects processing

This project has been conducted a few times at the first semester for students not being used to POPBL. The aim of this first semester project is to introduce the students to PBL and to facilitate understanding of and experience with PBL and group organized project work. The students should apply the theories and methods of PBL to a specific problem within their area of specialization in acoustics. The project work and supporting courses has its technical focus on basic signal processing and stochastic processes. Specific courses in acoustics are not given, as this semester is common for more specializations, but the project is within the specialization area, in this case acoustics.

This particular project was carried out at 2009 by three students (Jónsson et al. 2009) and is described in their abstract:

> The aim of this project is to design and implement different audio effects. The reason for this is give the group a better understanding of the field. Hence the goal is not the specific product but the knowledge acquired in the process. The work was done in two parts. A simulation part in MATLAB and a part with implementing in a DSP. The MATLAB part included delay, echo, reverb, tremolo and equalizer effects. Main emphasis was put on the reverb effect. The design of the reverb was basically a Schröeder reverb but the parameters were adjusted. The DSP part included delay, echo and tremolo. Main emphasis was on the tremolo effect. [...]

Audio Effects can be effects used by musicians playing electrical guitar, or a vocalist adding extra qualities to the voice. There is a large variety of effects so only a few can be implemented in the time frame of a student project. The first part for the project is to analyze and understand the need for these audio effects and the different types of effects. Effects can work in the time domain, such as echo or delay effects, or in the frequency domain such as equalizers and wah-wah effect, or in the level domain such as compressors, expanders, noise gates etc. Also artificial reverberation or room can be added to a signal. All of these effects are implemented using signal processing of some kind and most of them are only possible using digital signal processing. A number of effects will normally be chosen for an implementation and simulation, for example in MatLab. The students are also encouraged to do the implementation in a DSP system, as this is close to an electronic product, running in real time. During this project, the students succeeded to do both, a Matlab and a DSP implementation of several effects.

PBL in Fundamentals of Acoustics course

The course's purpose is for the students to achieve understanding of the fundamental concepts that underline basic acoustic principles. The course helps the students to achieve the necessary understanding of the physical phenomena involved in acoustics, together with the necessary skills needed for solving elementary as well as advanced acoustic problems.

The course consists of five two hour lectures, each followed by two hour exercise periods, where the students work in groups on problem solving or in laboratory experiments supervised by the teacher.

Due to the limited time of the course, it is impossible to go into detail on all of the relevant aspects of acoustics. Therefore the aim of the course is to provide the fundamental tools that can be used to develop the necessary knowledge needed to solve more advanced acoustic problems.

An example of PBL in the context of the course is the approach to the introduction of standing waves in a room. During the lecture the mathematical calculation of the modal frequencies is presented using the appropriate border conditions and a superposition of cosine functions as the solution to the three dimensional wave equation. This gives the students the mathematical tool to calculate the frequencies of standing waves in a rectangular room of specified dimensions. In the laboratory the students are asked to calculate specific normal modes of a room that is excited by a sub-woofer connected to a tone generator. The task in the laboratory is relatively “simple”: they have to calculate the lowest modes of vibration in the room and set the tone generator to the calculated frequency. Then, equipped with hand held sound level meters and their ears, they have to answer questions related to the acoustical phenomenon they are experiencing:

- How is the sound pressure distributed in the room?
- What is the meaning of the border condition used in the calculation of the normal modes?
- What is the influence of the position of the sound source?
- What is the relationship between the room's dimensions and geometry in the standing waves generated in the room?
- What is the influence of standing waves on the sound reproduced by a loudspeaker in a room?

These questions are not meant as a guide to what the students need to know about standing waves, they are rather aimed at starting a general discussion about sound in enclosures. Through this active discussion and hands-on approach, the students are able to make a solid connection between the theoretical approach to modeling the sound propagation within an enclosure (by solving the wave equation) and the physical implications of standing waves in a room. This leads to a higher level of understanding, where theory and practice are closely related. Based on this type of knowledge the students are able to go further and investigate on their own issues related to their project.

Project–Course Synergy

The material presented in the courses is broad and generally not specific for the requirements of each individual project. For example, in a lecture from *Architectural Acoustics*, the mathematical derivations of reverberation time are presented as well as standardized measurements procedures. In the exercises for the course, measurements of reverberation time in the laboratory are conducted, and the students have a chance to compare theory and practice. The students then have to make a decision as to how to assess reverberation time in relation to their project. Is it an important room acoustic parameter? What are the limitations of the measurements? What other acoustic parameters does reverberation time depend on? How should it be used in connection to the project? These and other questions are left for the students to find and answer.

In the courses *Human sound perception* and *Spatial hearing and 3D sound technology* the students learn (among other things) about spatial hearing, masking and loudness. These concepts are presented from the results of a series of documented experiments, giving facts about perception and the auditory performance of humans. The students have to contextualize this knowledge into the specific listening scenarios of their projects. For example, considering Case 1, to be able to explain the importance of lateral reflections in a concert hall and their significance to the perception of source width.

In addition to contribute with important aspects of the students' professional profile, the courses give general guidelines that shape, but not determine the direction the project takes.

The project cases presented here require competence in a number of disciplines that should be acquired during the semester. These are (among others):

1. Room acoustics and measurements of room acoustic parameters.
2. Calibration and measurement of electroacoustic transducers (Loudspeakers, headphones, and microphones).
3. Sound recording and reproduction techniques.
4. Human sound perception and psycho-acoustics.
5. Design of psycho-acoustic experiments and data analysis.
6. Signal processing.

WHERE DO OUR CANDIDATES GO?

At the master program all students will have attended the same courses and individual tests, but they will not have made the same projects and will have attended different bachelor programs often from another university. As a result, their individual profiles and interests within the field of acoustics, electronics and signal processing will differ.

Acoustics is an interdisciplinary area and candidates specializing in Acoustics may work as an engineer with people from other fields such as physics, electronics, architecture, medicine, psychology, mechanics and many more. Former candidates in Acoustics from Aalborg University are employed in many different types of companies or institutions in many countries and only few can be mentioned here.

Many are working within the electro-acoustics and audio equipment industry, for instance designing, hearing aids, audio signal processing equipment, audio equipment, the audio and signal processing part of mobile phones, measurement equipment, acoustical transducers (loudspeakers and microphones) and many more.

Acoustical consultancy is another big area with focus on architectural acoustics in construction and renovation of buildings but also with focus on noise exposure and its consequences e.g.: hearing damage and annoyance.

Many students in acoustics have a strong interest in music and often as active musicians, they will often be attracted to careers with relation to music, either as designer of music related products or as sound engineers.

Quite a few candidates continue their education in acoustics by acquiring a PhD. degree, either at Aalborg University that offers a 3 year program, or at other universities. This opens for a research career at a university or in industry.

CONCLUSION

Aalborg University's Master of Science Program in Acoustics is conducted as a Project Organized Problem Based Learning study. This study form is based on long term projects (lasting for an entire semester) and relatively few courses. This puts the bulk of the learning responsibility on the students, that must strive to achieve the necessary competences in order to fulfill the goals of the semester. This approach to higher education, pushes the traditional role of the teacher from knowledge provider to a facilitator.

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