PROCEEDINGS of the
International Symposium on Room Acoustics

15 to 17 September 2019 in Amsterdam, Netherlands

Room Acoustics teaching strategies at Federal University of Santa Maria (UFSM)

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ABSTRACT

This paper presents an overview of the methodologies employed in teaching Room Acoustics at the Federal University of Santa Maria (UFSM). Located in southern Brazil, it is currently the only undergraduate program in Acoustical Engineering in the country. Furthermore, some context is also given regarding graduate-level instruction. Throughout the work, the UFSM Acoustical Engineering course is presented as a whole. The active learning approaches used in Room Acoustics and related disciplines are discussed, as well. The tools developed in research and teaching contexts during these eight years of experiences are also presented, along with some feedback from students of the first semester of 2019.

Keywords: Room Acoustics, Teaching, Active Learning, Project Based Learning

1 INTRODUCTION

This paper presents the teaching and assessment strategies used at the Acoustical Engineering course (EAC) of the Federal University of Santa Maria (UFSM) in Brazil. It is mainly concerned about the subject of teaching Room Acoustics. The acoustical engineering undergraduate program is introduced in Section 2. The materials and computational tools developed are presented in Section 3. Section 4 covers the active learning and Project-Based Learning (PBL) strategies adopted during classes. Sec. 4 also confronts traditional theoretical exposition with PBL strategies and discusses strengths and weaknesses. Section 5 provides some students' feedback and discussion. Finally, Section 6 presents some final thoughts and remarks.

2 ACOUSTICAL ENGINEERING AT UFSM

The Acoustical Engineering undergraduate program at the Federal University of Santa Maria (UFSM) consists of five years (or ten semesters, in accordance with other engineering degrees such as electrical) of study. The course is part of the Technology Center (CT) at UFSM. The CT is the administrative structure that oversees all the engineering, architecture, and urban planning courses. The Acoustical Engineering course started in 2009 as part of the Brazilian federal government's REUNI program. This program has focused on the expansion of university-level education throughout the country. In the following sections, we present the course structure and the Room Acoustics related disciplines.

2.1 Course structure

As it is known (1), acoustics is a multidisciplinary area of knowledge encompassing the basic sciences and engineering, the biosciences (related to hearing and bioacoustics), the arts and even the geosciences. Our acoustical engineering course is no exception to that. On the other hand, as an engineering course, it is structured as such (according to the Brazilian standards).

During the first five semesters (1–5) students are required to undertake disciplines like Calculus (differentials, integrals, linear algebra, differential equations, complex variables), Physics (mechanics, thermodynamics, electromagnetism) and other basic disciplines for an engineer. An introduction to acoustics is also carried out during this initial part of the course in subjects like musical acoustics (6), introduction to acoustical engineering and through a discipline named: the noise, vibration and the human being – which introduces concepts such as noise and vibration, its measurements and possible effects on the human being.

During the 5th and 6th semesters, students start to get in touch with more specific disciplines, such as Fundamentals of Acoustics (5th) and Fundamentals of Vibrations (6th). Signal processing is also a big part of their formation through the disciplines: Introduction to Signals and Systems (6th), Digital Signal Processing I

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(7^{th}) and Digital Signal Processing II (8^{th}). The 5^{th} and 6^{th} semesters are a mixture of general engineering-related subjects (e.g. Circuit Analysis I and II, Basic Electronics, etc.) and those acoustics-vibration disciplines. Increasing hours are spent on specific topics as the student advances through the course.

From the 7^{th} semester onwards, students are required to take only acoustics related disciplines. These last two years include Noise Control, Vibration Control, Psychoacoustics, Electroacoustics, Sound Recording, Instrumentation, Numerical Methods in Acoustics and Vibration, Classical Experiments in Acoustics and Vibrations, Room Acoustics, Auralization, among others.

The course requires a total of 3375 classroom and laboratory hours during these five years. Students are also required to complete an internship outside the university (with many going even abroad, e.g. Germany, Thailand, Portugal, Holland, Denmark, USA, etc.). The 10^{th} semester is left only for this step (internship). Students must also accomplish a Bachelor Thesis (BT). This is, in general, a research work, advised by one of the professors. The BT is supposed to start at the 7^{th} semester and lasts up to the 9^{th} (7). It gives the opportunity for the student to engage in a long-term research and development project. It is our belief that a valuable Bachelor Thesis should, at least, touch on experimentation, numerical analysis and analytical analysis. Of course, depending on the nature of work, the student may gain experience in one area more than another. Students are strongly encouraged to develop their programming abilities during the BT (at least for data analysis). This is nowadays a very important ability for an engineer, and it tends to become even more essential.

The aforementioned is a very general overview of the course, with some of the discipline's names translated freely to be easily readable and internationally understandable. With this, it is possible to discuss in greater depth the Room Acoustics related topics within our course.

2.2 Room Acoustics specific subjects

The first Room Acoustics discipline starts during a student's 6^{th} successful semester within the undergraduate program. It is called Room Acoustics (RA) and only students approved in Fundamentals of Acoustics (5^{th}) are allowed to enroll in this course. The discipline comprises 60h, divided into 30 encounters of 2h each (twice a week).

This discipline's first unit starts by discussing the history of Room Acoustics (2). After that, the main physical phenomena related to Room Acoustics are introduced qualitatively. This includes sound absorption, specular and diffuse reflections, interference and its relation with complex number notation. The second unit covers the concepts of acoustical impedance, calculation of the surface impedance in multilayered media, measurement of sound absorption and modeling of absorbers (porous, perforated plates and membrane approaches). The third unit covers diffuse reflections, its underlying physical principles and diffusor apparatuses (e.g. QRDs, modulation and optimized diffusors). Units 2 and 3 also cover acoustic treatment-related topics.

From this point on, the course takes a path towards the calculation of the acoustic field in rooms. Unit four covers the low frequencies (modal behavior, analytical and some numerical methods) and the conditioning approach adopted for the low-frequency range. Unit five discusses geometrical Room Acoustics, its underlying principles and the main methods and tools available for design. Unit six covers statistical theory in Room Acoustics and calculating reverberation times based on mean absorption. The differences in geometrical and statistical Room Acoustics are pointed out. It is said that, although statistical theory disregards the room geometry and tends to be less precise, it is a good starting point in the design of a room. Unit seven presents acoustical objective parameters, their measurement and meaning from the psychoacoustics point of view. Unit eight closes the course discussing general guidelines on several project cases (e.g. concert halls, studios, classrooms, restaurants and so on). In Section 4, the methodology used during teaching is discussed more in detail.

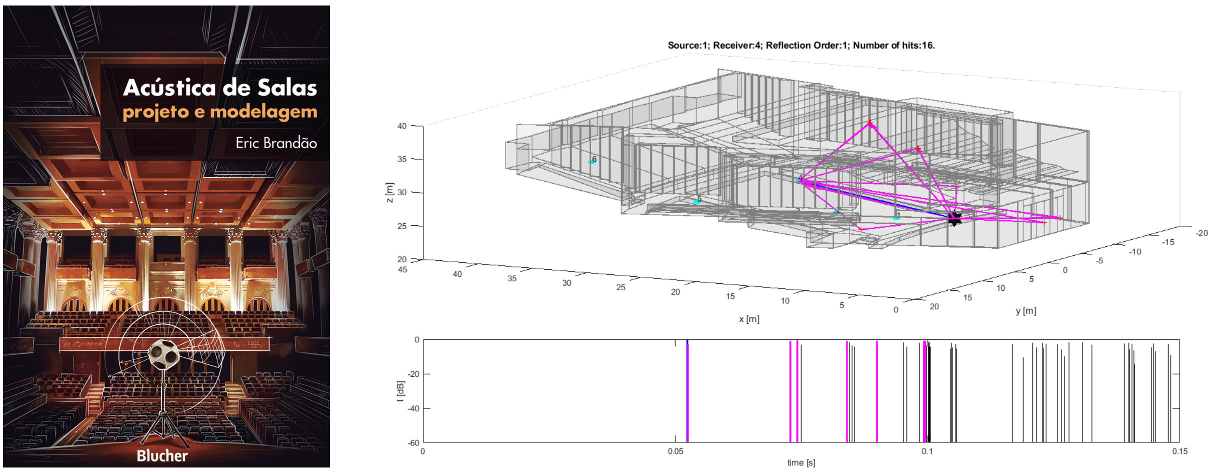
Some disciplines interface very strongly with Room Acoustics. For instance, during the 7^{th} semester, students enroll in a discipline called Instrumentation for Acoustics and Vibration. During this subject, they learn microphone operation, calibration and sound field correction. In the 8^{th} semester, students engage in Auralization and Digital Signal Processing II (DSP II). In this discipline, students are required to perform experiments on measuring impulse responses (IR or RIR). The rooms are case studies in which the undergrads perform the whole spectrum of measurement (with sweep signals, for instance), process the measurements, obtain impulsive responses (mono and binaural) and objective parameters. ITA Toolbox (3) is commonly used for the generation and acquisition of signals, helping students to carry out the post-processing. In Auralization, students get more in-depth studies of the spatial audio, binaural technology and binaural room impulse response measurement and simulation (BRIR). They apply/combine knowledge from Room Acoustics discipline and use DSP II measurements.

There are also other disciplines that may have a less specific interface with Room Acoustics. In sound system design, the themes discussed have an obvious interface with Room Acoustics. In psychoacoustics, many themes discussed also have correlations with Room Acoustics. Furthermore, subjects like noise control and sound insulation may use concepts discussed in Room Acoustics, like sound absorption and the influence of reverberation.

3 MATERIALS DEVELOPED

The work involved in breaking ground on the acoustical engineering course in Brazil may be very challenging to professors and students. Most of the technical literature available is written in English. Considering the diverse background of students, with many of them coming from underprivileged socio-economic situations, it is no wonder that difficulties exist with acquiring or learning in their non-native language. Moreover, much of the literature in acoustics may be very advanced for an undergrad course. Learning English is encouraged, but the professors do undertake the job to produce good readable technical material in Brazilian Portuguese. In 2016, one of the professors authored the first technical book (*Room Acoustics: project and modeling*) entirely dedicated to Room Acoustics (4). With eight chapters and 655 pages, it covers the units taught in the Room Acoustics discipline (observe Fig. 1 (a)). In 2017 the book won the 59$^{\text{th}}$ Jabuti prize, a prestigious literary prize in Brazil.

Another battlefront for the professors is computational modeling in Room Acoustics. There are several reasons to engage in such a task. First of all, the acoustical engineering has a license for Odeon 11 (5). In that sense, students are encouraged to learn how to use Odeon. They have at least one major project to fulfill during the Room Acoustics discipline using computational modeling (per Sec. 4). One of the challenges we face now is the cost to keep our license up to date. With economic instabilities in the country, the exchange rates from Brazilian Real to dollar or euro creates an even worse scenario in this regard. Another challenge concerning teaching is that only one hard lock is supplied with our license of Odeon. This means that only one student or group of students can run simulations at a time. Those reasons have directed part of our efforts towards writing a software for Room Acoustics simulation. The current version is solely based on ray-tracing. The first results of this task were published at ICA 2019 (8) and an illustrative result is shown in Fig. 1 (b). Right now, there is a lot of work being produced to make it an available and usable tool for our students in the near future. Currently, the code is being re-written in Python and C++. The goal is to make it free for research facilities and/or non-commercial purposes. Of course, it is our plan to further improve the computer model as a research activity and to include several other tools in the code, such as a hybrid geometrical acoustics module.



(a) Book cover.

(b) Example result from of the software developed.

Figure 1. Book cover and numerical software used for teaching and research.

The other professors of Room Acoustics-related disciplines are also contributing with material to the topic (7). This involves reading the material in the form of professor's hand-written notes, creating impulse response measurement databases, and developing computer code for diverse tasks (e.g. statistical analysis, loading and dealing with Head-Related Transfer Functions, etc.).

4 TEACHING STRATEGIES

It is difficult to find references for teaching and assessment strategies for an undergraduate course in acoustical engineering. Throughout the world and Brazil, there are a good number of classical engineering courses, such as civil, electrical and mechanical. Acoustics, on the other hand, is frequently taught only in graduate-level instruction (in many places). This was the case in Brazil until 2009 when the undergraduate program in acoustical engineering at the Federal University of Santa Maria (UFSM) was created (9).

Researching available scientific literature reveals papers concerned with the teaching of acoustics. In 1968, Lawrence (10) discussed the teaching of architectural acoustics for architects. The major difficulty she found was associated with the mathematical load of acoustics confronted with the background of architects. This is not our case in the undergraduate course, since the first semesters are designed to give students a solid mathematical foundation. However, this situation may be a challenge at the post-graduation level, since there are no post-graduation programs specific to acoustics in Brazil. The professors of the course do teach and advise at the graduate level but usually within civil, mechanical and electrical engineering programs. This means that graduate students may join the course from a wide range of different curricula.

There are also other papers concerning teaching demonstrations in Room Acoustics (11, 12), but no specifics to course strategies are discussed. Recently, Llorca, Redondo & Vorlander (13) published a paper discussing some demonstrations for architects and some active learning strategies (14). Active learning is a very interesting paradigm since it tends to engage students more. There are also other applicable teaching and assessment strategies for active learning and problem (or project) based learning (PBL) (15–17). These last papers are specifically applied to digital signal processing, but the insights are useful in any manner.

Across the spectrum of teaching Room Acoustics at the acoustical engineering course, the job is mainly divided into three disciplines: Room Acoustics, Auralization and Digital Signal Processing II. Some of the strategies used in Auralization and DSP II has been briefly discussed already. Now, we turn our attention onto the Room Acoustics discipline.

During the Room Acoustics semester, the instructional focus is more theoretical, computational and project-oriented. It is our belief that at this stage, students need a firm theoretical background in Room Acoustics, which complements the discipline of Fundamentals of Acoustics. More measurement practice is accomplished later during Auralization and DSP II.

Theoretical background in Room Acoustics is accomplished mainly by traditional exposition to concepts, mathematical derivations and numerical demonstrations. This approach does not tell the whole story, however. Students are required to engage in conceptual discussions, as well. This is achieved in a few ways according to class dynamics. Some of the strategies and examples are listed in Table 1.

The traditional exposition method is complemented by a project-based learning (PBL) strategy. As part of the assessment, students are required to form groups of three and project a room acoustical design from scratch. This is the semester's project. In order for guidance, the teams are formed at the beginning of the semester. The whole class is assigned with several fairly open options for projects such as classroom, cinema, restaurant, small control room of a studio, big control room, recording room, concert hall, multipurpose auditoria, etc. The professor is also open to suggestions. Out of curiosity, a team in this semester proposed to design a Buddhist temple. Beyond the general projects, each proposal must comply with some general dimensions. The project consists of five steps. First, as a warm-up work, each team uses the Delany and Bazley model (18) to calculate the sound absorption of some porous sample configurations. The second phase consists of literature research in order to better understand the general guidelines for the project chosen by each team. This includes a typical floor plan, materials, reverberation time, and searching for photographs and technical drawings. The third stage is to analyze the low-frequency behavior of the room and to propose acoustic treatment to correct for possible problems. This is demanded to be done for an approximately rectangular room at least. However, it is frequent that more curious/investigative teams try to use some FEM or BEM simulation. The fourth stage is to perform reverberation time analysis using statistical theory. Teams are required to analyze a room prior to acoustic treatment, assess if it conforms with their expectations from phase 1, and to propose acoustic treatment to correct the room's acoustical response. Teams are required to use Sabine and Eyring formulas as well as another of their choice. Students are encouraged to write their own computer code to perform the calculations in phases three and four. The fifth and final stage consists of using geometrical acoustics (currently with Odeon) to build and analyze a 3D model of the room, to perform optimizations and come up with a design of choice. In every stage, students are required to present their findings to the whole class and to the professor. Errors and necessary improvements are discussed during this time. Additionally, the professor is readily available to alleviate any doubts (conceptual or regarding their project). Over the last two years, more experienced students also engaged as assistants to the teams.

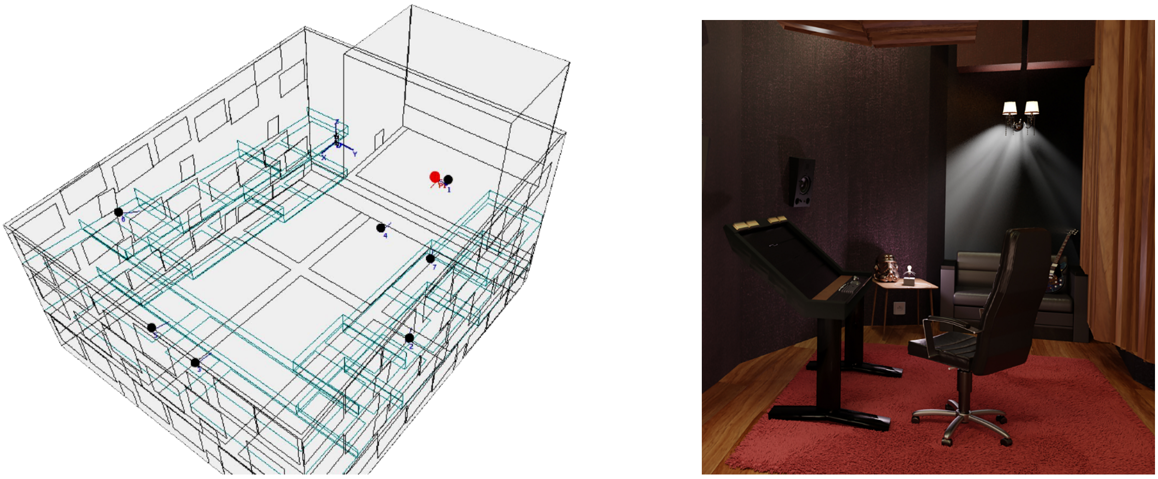
Figure 2 shows the results from two teams during stage 5. The first is an Odeon model of a concert hall. The second is a visual rendering of a small control room of a studio – done with Blender. The visual rendering was an initiative of the team (non-required work). Of course, the team also performed the required acoustical analysis.

Table 1. Strategies for an active learning approach to theoretical exposition in Room Acoustics.

Method	Example
Mounting deep concepts in steps: students are asked a series of questions to mount a scenario in their head;	Consider the calculation of the absorption coefficient of a porous sample. It involves knowing the difference between material properties (characteristic impedance, wave number) and mounted apparatus properties, such as surface impedance, reflection coefficient and absorption coefficient. Students may be asked which quantities do not depend on the way the material is assembled. This, of course, should be calculated first. In addition, students are asked if one changes the mounting characteristics what quantities change and what is expected to happen.
Ask for students' intuition about a problem or concept and build upon it; or ask deeper questions, so that they are able to recognize mistakes and move on;	Once Sabine's formula for reverberation is introduced (Eq. (1)), the professor may ask for dimensional analysis. It will be easy to conclude that the [s] in T60 on the left does not match the [m] on the right. The next question is, where does the [s] come from. Coming back to derivation allows one to see that the number 0.161 has [s/m] dimensions with the speed of sound in it. The student can also be asked what happens to 0.161 if temperature changes and why those quantities should be measured when measuring absorption in reverberation rooms.
Ask a question and call for a vote from the whole-class – frequently there are some disagreements on the correct answer and students are required to reason why they pick a particular answer before the professor can argue on the correct one;	Ask the class if it is the diffusion coefficient (Γ) or the scattering coefficient (s) that is used in geometrical acoustics simulations. The responses may be surprising, since many may think that the Γ easily codifies the reflection direction, which is not the case. This is also an opportunity to re-discuss the definition of the scattering coefficient and its limitations on modeling Room Acoustics.
The most important mathematical equations are analyzed term by term with the class, so students may understand what a Greek letter has to do with the real world.	Take, for instance, the calculation of sound pressure from modal expansion (Eq. (2)). On one hand, there is a sum that goes from 1 to infinity, which shows us it is necessary to sum the contributions of all modal functions. On the other hand, in the denominator of each sum term, there is a difference between the modal wavenumber and the wavenumber of the frequency being calculated. This denominator difference shows that as the modal frequency gets very different than the frequency being analyzed, the influence of that mode to the acoustic pressure gets lower. Furthermore, resonances appear in the FRF when the modal wavenumber and acoustic wavenumber are equal – corresponding to a peak in the magnitude of the FRF, since this part of the denominator goes to zero.

$$T_{60} = \frac{0.161\, V}{S\, \bar{\alpha} + 4mV} \tag{1}$$

$$\tilde{P}(\mathrm{j}\omega) = \frac{\mathrm{j}\omega\rho_0 Q(\omega)}{V} \sum_{n=1}^{\infty} \frac{\psi(\vec{r}_{\mathrm{s}})\, \psi(\vec{r}_{\mathrm{r}})}{k_0^2 - k_n^2 - 2\mathrm{j}k_n\eta/c_0} \tag{2}$$



(a) Odeon model of a concert hall.

(b) Visual render of the model of a small control room (done with Blender).

Figure 2. Some designs made by students in the first semester of 2019.

5 STUDENT FEEDBACK IN 2019

With the upcoming International Symposium on Room Acoustics in Amsterdam, 2019, the professor of Room Acoustics asked his students to provide some feedback regarding the teaching strategies adopted. A simple google forms questionnaire was drafted and sent to the students. From the 25 students enrolled in the discipline during the first semester of 2019 (March to July), there was one who withdrew. Thus, 17 students answered the anonymous statements in the questionnaire.

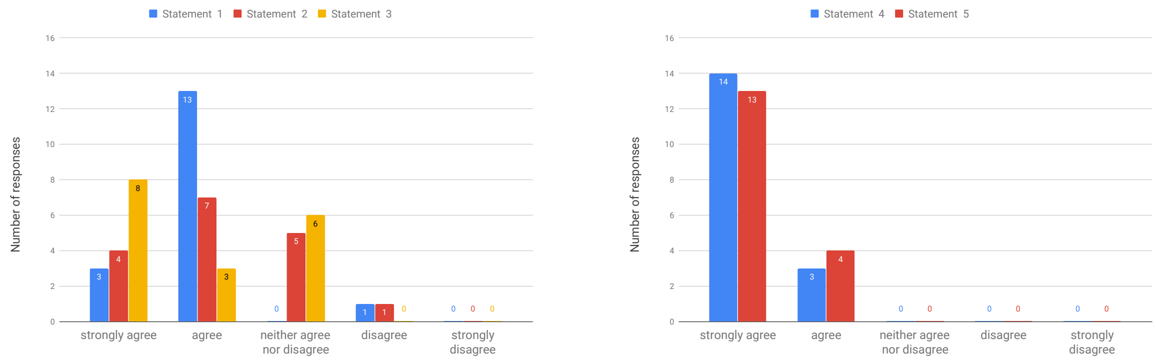
The answers are given in Figure 3. The questionnaire was structured in terms of statement quotes with which students: (a) strongly agree, (b) agree, (c) neither agree nor disagree, (d) disagree, (e) strongly disagree. The statements were very simple and created just to provide a general impression. In Fig. 3 (a) the statements were:

- Statement 1 (blue) – I was able to reach the desired comprehension level of Room Acoustics.
- Statement 2 (red) – It was easy to find support material for the project.
- Statement 3 (yellow) – Having fewer theoretical classes and more project practices would help me achieve a deeper understanding of Room Acoustics.

Statements 1 and 2 were intended to provide feedback on the level of comprehension students feel they reached and on how easy they found to do the necessary research for the project. Regarding statement 1, only 1 student felt left behind; the other 16 respondents either agreed or strongly agreed on reaching a good level of understanding on Room Acoustics.

Regarding statement 2, the responses were more scattered with 6 students feeling unsure about how easy it was to find material to do the project well. At the beginning of the semester, all students receive an obligatory reading list (mostly from (4)) and a complimentary reading list. This list contains sections or chapters of books and articles covering each of the 2 h encounter themes. The scatter in responses to statement 2 shows that: (i) either the method of providing the list is ineffective; or (ii) that students don't look to the list too much; or (iii) that they feel overwhelmed or lost with the amount of information they find; or even that (iv) it is hard for students to distinguish between valuable and non-valuable information when they search for themselves.

Statement 3 was designed to assess how students felt about the number of theoretical encounters. The answers reveal that they would prefer to have more practice-oriented activities. On the one hand, this is designed to increase their operational ability (like software operation and data analysis). On the other hand, it is the belief of the professors who are gravitating entirely towards Project-Based Learning at the expense of theoretical teaching, there may be a downside to leaving firm theoretical ground uncovered. This is an important part of an engineer's formation and allows any well-trained human to more easily draw inferences on new problems that may be found in the future (19). Finding a balance in this matter is not an easy task (7). Right now, the professor's choice is to invest time to provide firm theoretical knowledge in an active way, so that students may be able to do a critical-thinking analysis on the new problems they find. The five-year engineering course is supposed to provide students with ample opportunity for this, and they may acquire a vast dataset of



(a) Statements 1, 2 and 3.

(b) Statements 4 and 5.

Figure 3. Answers to the statements in the questionnaire.

experiences during their internship and professional life. Nevertheless, frequently, it is harder to gain theoretical knowledge along with professional life (work), adult life, family and other duties to attend.

In Fig. 3 (b) the statements were:

- Statement 4 (blue) – Using the project as part of the assessment is a preferable learning strategy to traditional written test.
- Statement 5 (red) – To develop the project from the begging to the end helped me to understand the theoretical aspects exposed.

The responses to statement 4 show that the absolute majority of the respondents felt that doing the project is preferable to a written test. Students were also required to take two theoretical tests during the Room Acoustics course. In other case scenarios, students preferred written tests. This happened not because these students felt that the test was a better learning strategy, but because written tests meant a lesser work burden for them (7). The responses to statement 5 showed that students feel that doing the project helped them to grasp the theoretical knowledge in further depth. This is related to the answers to statement 3, since they may prefer more project practice-related activities in order to strengthen theoretical knowledge. The problem with that line of thought is that diverting time towards more practical activities would imply in less time diverted to the theoretical discussion. This, in turn, would lead to less theory to acquire, to begin with.

Finally, the questionnaire also allowed for written comments at the end. In the following are some of the quotes of students (freely translated). This helps further strengthen the discussion.

"A bold suggestion, the cherry on top. Some alternative to Odeon would be cool, where numerical simulations could be easily implemented. I offer all the support for the software being developed in-house."

"In general, the discipline was exceptional. It was taught with mastery. The Project helped a lot in the comprehension of many things. My only problem was to access Odeon. Having a single hard lock and given the limited amount of time made the schedule of all very tight."

"Making the projects of past semesters available to consult would help make mine better."

6 CONCLUSIONS

course in Brazil. The active learning paradigm strategies adopted during the theoretical exposition have proven to be an effective teaching method. This is complemented by a PBL approach, where the class is divided into teams. Each team has to do a Room Acoustics project from scratch. Students seem to enjoy this process and even crave for more practical activities. The balance between theoretical exposition and practical activity is difficult to find. It is our belief that firmer theoretical knowledge complemented by practice is the best approach. Furthermore, the professors of the course make an effort to program activities in other disciplines that relate to theoretical exposition to Room Acoustics. This is the case, especially for the disciplines Auralization a Digital Signal Processing II, which complements many of the expositions in Room Acoustics.

ACKNOWLEDGEMENTS

The authors would like to thank the Acoustical Engineering course (EAC), the Technology Center (CT) and the Federal University of Santa Maria (UFSM) for the financial support to attend this symposium and to present this paper. We also thank the event organizers for accepting the paper as a late submission.

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