Inaugural lecture prof.dr.ir. Ines Lopez Arteaga

Sound connections

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Introduction

Mr. Rector Magnificus, ladies and gentlemen,
Let me start by sharing with you why I ever dreamed of becoming a professor at a university. As a 16-year-old girl I realized I wanted to do research and spend my life learning new things and sharing this knowledge with others. Later I discovered that this is exactly what universities do: generate new knowledge and share it. As a matter of fact, since the Middle Ages. when the first universities were founded, their mission has comprised research, education and public service [1]. And this perfectly matches my personal mission: to **learn** by doing research, to **share** my knowledge by lecturing and publishing, to **inspire** students and colleagues to learn and to pursue their ambitions, to **contribute** to progress in society, and in this way to make a difference. Therefore, as the Dutch would say, I am an academic “in hart en nieren”.

Figure 1

Personal mission.

In this inaugural lecture I will start by introducing you to my field of research, engineering acoustics, to show the relevance of acoustics to society. I will share my view of acoustics as a connecting factor between disciplines and application areas and my opinion of the importance of system thinking in this field. Thereafter, we will move on to my other passion, sharing knowledge, and, more specifically, on to the challenges and opportunities created by digital and online education. Finally, I will present my views on the need for our university to develop into a diverse and inclusive organization in order that it can fulfill our ambitions to inspire and innovate in today's globally connected world.

The importance of sound connections

Sounds are a product of human activity and are always around us. Unlike our eyes, we cannot close our ears. During an average day, we are exposed to sounds from many sources, among them household equipment, transportation systems, people around us, and ourselves.

Figure 2

Sounds are always around us.

Most of us perceive unwanted sounds (noise) as annoying but harmless. However, excessive noise levels affect the economic and technological development of western countries in many ways. In 2020 noise pollution will be the main environmental problem in the Netherlands, outstripping air pollution as the number 1 cause of environment-related health problems [2]. In a report of the Dutch National Institute for Public Health and Environment (RIVM) [3] it is concluded that “Noise exposure and its associated disease burden will probably increase up to a level where the disease burden is similar to the disease burden attributable to traffic accidents”. Around 60% of European citizens living in urban areas, which represents around 125 million people, are exposed to noise pollution from transport at levels that are thought to be disturbing, and which may have an impact on their health [4]. Overexposure to noise can lead to, for example, heart attacks, high blood pressure and poor learning performance. We could say that noise is a *silent killer*.

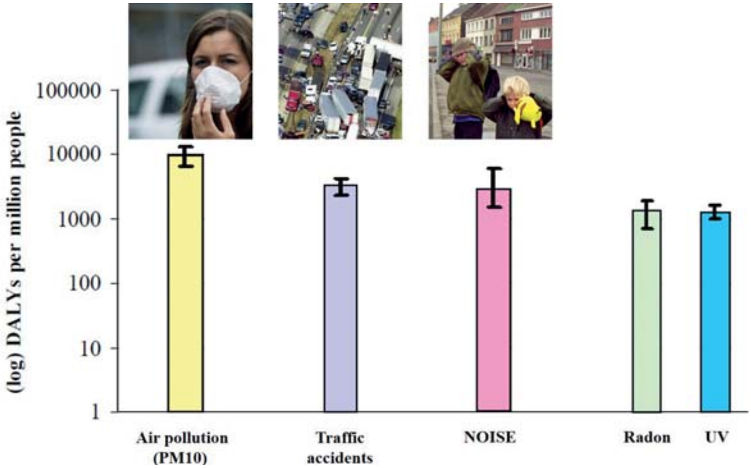

Figure 3

Noise as a major cause of loss of healthy years of life in 2020.

As a consequence, noise regulations are imposing increasingly stringent demands on the noise emissions of transportation systems, machinery, and consumer products (from cars to electric toothbrushes). At the same time, vibrations and acoustics can pose a threat to the integrity and proper operation of many engineered systems, causing the failure of complex systems like turbines and limiting the performance of high-tech precision machinery.

A complicating factor in the process of developing and implementing low-noise solutions is that in most applications the acoustic performance of the system is not the primary performance goal. For example, in a car the primary performance goal is to take us from one place to another in a safe way, the next priorities are energy efficiency and handling performance, and somewhere down on the list we will find acoustics. As a consequence, the overall system design, the weight and space constraints are already set by the time the acoustic engineers get involved, which requires them to be able to understand the functioning of all parts of the system and the interactions between them in order to be able to develop feasible solutions. Therefore, engineering acoustics requires a broad understanding of system design (system thinking).

From the point of view of research in engineering acoustics, although, as we will see later on, the physical process of noise generation is similar in most engineered systems, every system requires a tailored approach to the understanding of noise generation and the development of suitable solutions. In the current academic climate, where narrow specialization fields are highly valued, it is tempting to choose one specialization field, either from the basic research perspective (acoustic materials [5,6], array processing techniques [7,8]) or from the application perspective (railway noise [9], musical acoustics [10]). Although fundamental research advances are needed to increase our understanding of acoustics, excessive specialization is a threat to innovation, since it leads to islands of knowledge, with researchers working within their sub-field not knowing that in the sub-field next to them the solution to their problem is at hand. Therefore, as well as fundamental research advances, we need a global understanding of sound generation in engineered systems. This will enable us to optimally exploit the cross-links between application areas and reach innovative acoustic solutions. This is what sound connections is all about.

Figure 4

Acoustic and vibration disturbances can cause failure of complex systems.

How sound connections work

In engineering, acoustics connects seemingly unrelated worlds. Although engineered systems are very diverse (just think of a tooth brush and a cruise ship), noise generation is often governed by the same basic principles. Let me illustrate this with an example. If I ask what the sound of a double bass and the sound inside a car have in common, your most likely answer will be “nothing”. While the truth is that they have everything in common. Starting at the source, in the double bass the strings vibrate due to the interaction with the bow, while in a car the tires vibrate due to the interaction with the road. These vibrations are transmitted to the car-body through the suspension, while in the double bass the string vibrations are transmitted to the belly through the bridge. Finally the vibrating belly of the double bass radiates sound we call music and the vibrating roof, windscreen and doors of the car radiate sound we call noise. Nevertheless in these two cases sound is generated in exactly the same way. Consequently, the design of the bridge of a string instrument can be optimized to produce the desired timbre [11] by applying the same methods as would be applied to the design of suspension elements to reduce noise inside a car [12]. The only difference is that in the case of a musical instrument our goal is to enhance the sound while in the case of the car we aim to minimize the noise coming from the tires.


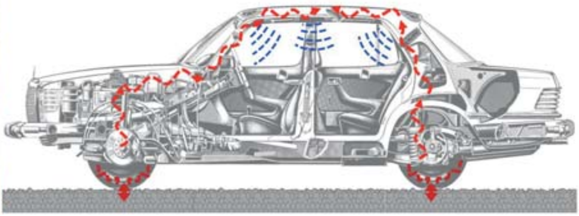

Figure 5

Sound: double bass and noise inside a car have everything in common.

This type of sound generation process involves what we call structure-borne sound and it occurs in many other systems, from tooth-brushes to buildings. Other sound generation mechanisms are found in a wide range of systems. Looking at

acoustic problems from the point of view of the sound generation mechanism is one of the ways in which connections may be established and solutions translated from one application field to another. An example of this is the randomization of the CVT belt profile inspired by the randomization of tire treads [13].
In my research, I concentrate mainly on understanding how noise is generated and on developing models that describe and predict the system behavior. The special characteristic of the models we use is that they are based on a description of the system in terms of basic patterns or base functions (modes, waves, Fourier components ...) and exploit the fact that the system response can often be captured with a limited number of base functions. One could think about these base functions as building blocks or pixels in a digital photograph. Imagine that in the case illustrated in Figure 6 we are only interested in knowing whether the object in the picture is a car or not. Then the right photograph contains enough detail for us to establish that what we are seeing is a car. However, if we need to know what type of tire rims this car has, we would need the photograph on the left. The number of pixels we need, therefore, depends on the question we are trying to answer.

Figure 6

Required level of detail depends on goal.

In acoustics the building blocks are not pixels but patterns, as shown in Figure 7 for a guitar. The main advantage of using these base functions to model vibrations

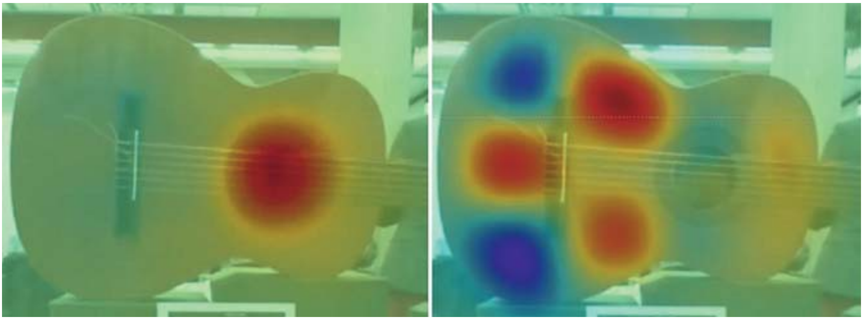

Figure 7

Example of basic patterns for a guitar.

and acoustics is that often the response of the system can be described using only a few of these functions. We have applied this concept to reduce squeal noise in train wheels [14], explain the response of vocal folds [15], model the response of rolling tires [16], and understand noise emission from electromagnetic motors [17].
Sound connections.
In the next sections I will use two examples to illustrate the innovation potential of sound connections: acoustic cameras as contact-less vibration sensors, and road design for sustainable ground transportation.

Acoustic camera as vibration sensor

The patterns shown in Figure 7 are sound images measured using an array of microphones, also known as an acoustic camera. This is how acoustic cameras are commonly used: to make images of sound. However, microphone arrays also have the potential to accurately measure vibrations, especially when the vibration patterns one would like to detect are known. In that case, we can combine our knowledge of the sound patterns in the air, measured by the array, with our knowledge of the vibration patterns in the structure in order to accurately measure vibration levels.

This novel idea is applied to measure vibration levels on a chuck (the table that carries the wafer in a lithography machine) with nanometer accuracy [18]. In the figure below, the experimental setup and the vibration patterns measured are shown. With this method we are able to measure local deformations of the chuck down to 10 nanometers with 90% accuracy.

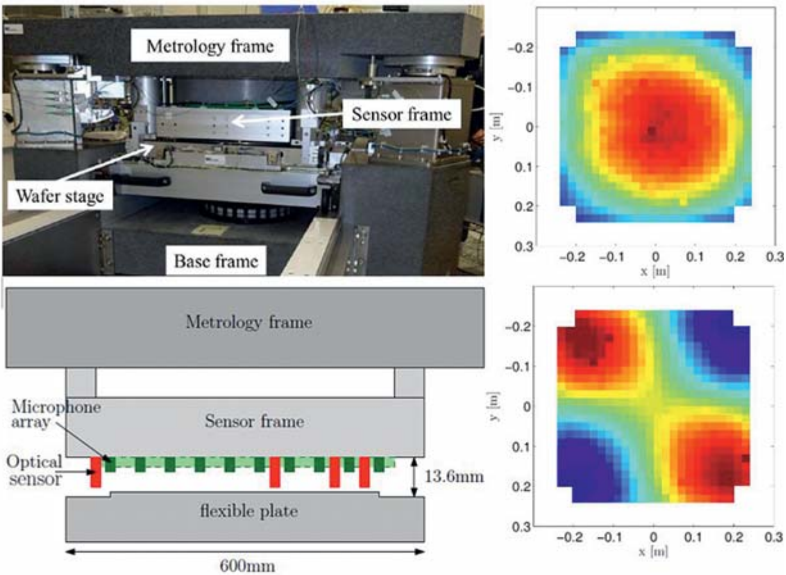

Figure 8

High-precision vibration pattern identification. Photograph and schematic drawing of experimental setup (left) and vibration patterns chuck (right).

Following a similar line of thinking, we have developed a method we call Wave Signature Extraction (WSE) to determine the contribution of the rail to the total noise measured when a train passes by (pass-by noise) [19]. In Figure 8 the line array used in the measurements can be seen pointing at the empty track (left) and when the train is passing by (right). For the empty track, the array detects the vibration pattern of the rail (bottom left), and this information is used to extract the contribution of the rail from the total pass-by information (bottom right). The rail contribution is measured with an accuracy of 1 to 3 dB(A), depending on the frequency. The advantage of this method compared to current methods is that it does not require any information about the track condition, which avoids having to access the track for additional measurements.

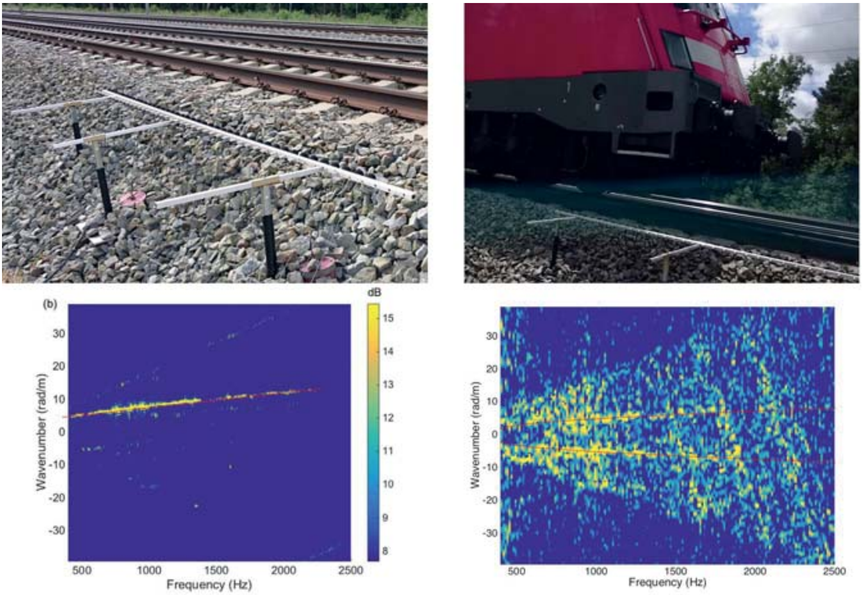

Figure 9

Wave field separation (WSE) for rail noise detection. Array pointing at empty track (top left), vibration pattern of empty track (bottom left), train passing by (top right), total sound pattern during pass-by (bottom right)[20].

This kind of thinking, where knowledge of the patterns of vibrations is combined with knowledge of sound patterns in the air (or water), can be applied to develop new solutions to many other problems such as condition monitoring and pile driving.

Road design for sustainable ground transportation

Road traffic noise is becoming an increasingly significant problem in densely populated areas. This noise consists mainly of tire/road noise and engine noise, but tire/road noise is the dominant noise at constant driving speeds of 40 km/h to 130 km/h [21,22], while engine noise dominates below 40 km/h. This implies that electric vehicles, where there is no engine noise, can help reduce noise levels in residential areas and city centers, where the speed limits are below 50km/h, but not for people living close to beltways and highways. However, there is more to sustainable road transportation than solving the noise problem. In Europe, 18% of total CO_2 emissions originate from road transport. In order to reduce fuel consumption and, therefore, emissions, the energy losses in vehicles should be minimized. One could argue that the answer to the challenge of reducing CO_2 emissions from road transport is electric vehicles, but this only makes reducing energy losses in vehicles even more relevant. Why? Because reducing energy losses leads to a larger radius of action of electric vehicles, which in turn will accelerate the increase of the electric vehicle fleet in Europe. Rolling resistance is an important factor in this respect since, depending on the driving speed, it accounts for approximately 20-30 % of the energy consumption of a typical passenger car. Therefore, in order to reduce both noise emissions and energy consumption, a good understanding of tire/road interaction and of the influence of tire and road properties is needed. In this inaugural lecture I will concentrate on road design.

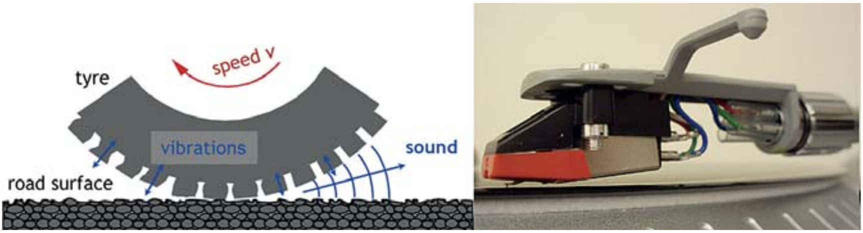

Figure 10

Tire/road noise generation is similar to how an LP player works.

Tire/road noise is caused by the interaction between road and tire (see Figure 10). When the tire rolls on the road, the roughness of the road surface forces the tire to vibrate and these vibrations generate sound that is amplified by the wedge between tire and road at the leading edge of the tire. This sound generation process is similar to how an LP player works, where the roughness of the track forces the needle to vibrate and this vibration is transmitted to the loudspeaker, which amplifies the sound. Based on our understanding of the sound generation process, there are two things we can do to reduce noise: make the roads as smooth as we can to reduce tire vibrations, and increase the sound absorption of the road in order to reduce the sound amplification. This is not possible with a single-layer asphalt road, since small stones are required for smoothness but large stone are required for sound absorption. Therefore, the idea of double-layer porous asphalt was born, with an upper layer of small stones for smoothness and a second layer of large stones for sound absorption. This is what we call silent asphalt.

Unlike our understanding of tire/road noise, our understanding of how road properties influence rolling resistance is limited. We know that rolling resistance is caused mainly by the energy losses due to the large-scale deformation of the tire in the contact region caused by the load of the vehicle. However, the small-scale deformation of the tire tread due to the interaction with the road surface is also a source of rolling resistance. An extensive experimental campaign in the Netherlands on 42 different road surfaces [23] showed that rolling resistance increases as the roughness of the road surface increases, and that some rubberized (flexible) roads lead to a lower rolling resistance than regular asphalt roads [23]. Although tire manufacturers know how to optimize their tires to reduce energy losses due to large-scale deformation, very little is known about the

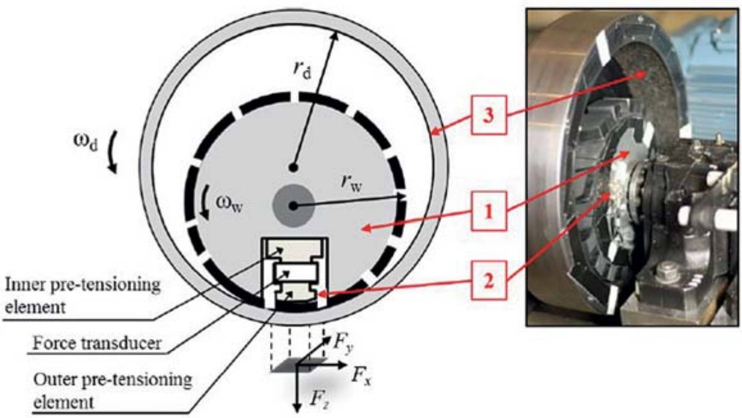

Figure 11

Compact Internal Drum (CID) test-rig at KTH Royal Institute of Technology.

contribution of road surface roughness. We have developed models to try to understand and predict this contribution [24], and have recently designed and built an experimental setup (Figure 11) that will allow us to zoom in on the contact zone and explain how the interaction between tire tread and road surface roughness leads to energy losses [25].
Zooming out again, understanding how road properties contribute to energy losses in vehicles will open up a completely new range of possibilities, some of which we can foresee while others are yet to be discovered. It will, for example, make low-energy road design possible, thus allowing government agencies to include energy consumption considerations in their long-term road network development plans; it will allow policymakers to develop energy labels for roads; and knowledge of these road energy labels can be implemented in the navigation systems of vehicles to minimize energy consumption on long-distance routes. Taking one more step back, we should also invest in learning about the trade-offs between safety, low noise and the low energy consumption of roads, and work towards designing not *silent roads* or *low-energy roads*, but a sustainable road transportation system that ensures a safe and healthy living environment for us all.

Figure 12

Sustainable transportation.

Education in a connected world

As I mentioned in the beginning of this lecture, part of the mission of universities is to *share* our knowledge, and educating students is our main means of doing so. Eindhoven University of Technology consciously chooses to be a university “where people matter”. Our long-term vision includes on-campus teaching, individual mentoring and supervision, and involving students in our research. Because we believe the university is the place where students are formed as engineers and grow as human beings [26].

In the early Middle Ages, there were a few centers of learning in Europe, *studia generalia*, that gathered scholars from all over Europe [27]. Each teacher had their own group of students that would follow them as they moved around Europe, and universities would compete to attract the most popular teachers [28]. The “nomadic” habits of masters and students came to an end when more and more translations of written texts appeared in the 13^{th} century. By the early 14^{th} century, a master was expected to know a considerable quantity of standard texts, which made it convenient to be close to a library and to other teachers with whom he could exchange ideas and books [28].

Figure 13

From the Middle Ages information has been tied to a physical location.
Left- Library of Leiden University 1610 (www.alamy.com),
Right- Library of Eindhoven University of Technology 2017.

For many centuries access to knowledge and information has been tied to a physical location and this has shaped academic education. Today, thanks to the capabilities of smart phones and extremely rapid Internet developments, knowledge is available anytime and anywhere, and followers from all over the world can virtually travel to the most popular teachers. Are we back at the Middle Ages? Well, not really, but the role of universities as physical centers of knowledge is no longer obvious. We are witnessing a new hype in forms of learning, now free from hard copy, based on the rupture of space and time [29].

Over the last 10 years the Internet-based educational offering has developed quickly: Massive Open Online Courses (MOOCs), online courses [30], micromasters [31] and nanodegrees [32] are some examples of the vast range of online possibilities. All these examples correspond to full online educational activities, where students do not need to physically set foot in an academic institution. The obvious benefit of this type of education is that it gives millions of people in developing countries access to excellent and affordable higher education.

However, the question is, given these trends towards the globalization of education, how can our university distinguish itself as the university where people matters? By organizing our education such that our on-campus activities focus on creating unique added value for our students and moving all other educational activities to the digital (online) domain. This requires, for example, developing a complete digital learning environment that not only offers online learning material, but also monitors student activity and progress in order to adapt their learning environment to their needs and capabilities. In this way, the costly on-campus educational time can be invested in complementary activities that aim to activate and motivate students to develop a deeper understanding of the subject matter.

At present, hybrid learning forms that combine traditional, space and time-bonded education with digital and web-based tools are gaining in popularity. Plasencia and Navas [29] speak of Augmented Learning to describe learning that extends beyond traditional education by making use of computers and new digital media supported by ever-present global connections. These new learning practices are not tied to a specific location nor to a formal schedule and require only access to a broadband internet connection. Teaching and learning practices that combine online learning with in-class activities are known as flipped classrooms or blended learning.

The basic idea of blended learning is that the actual lecture, in which concepts are explained, takes place in the digital environment in the form of web lectures. These are supplemented with online learning materials and the in-class activities are designed to anchor the concepts learned online and attain deeper knowledge. For example, in my course 4DB00 Dynamics and Control of Mechanical Systems, students watch web lectures, answer online questions and study pre-solved examples before the physical lectures, while in-class specifically designed quizzes are used as a formative assessment and peer-instruction tool [33]. Although more

Figure 14

Blended learning.

and more lecturers at our university are expressing interest in transforming their courses into blended learning courses, still only very few courses are taught this way. The main bottleneck most people mention is lack of time and resources, which certainly pose a serious limitation. The available financial support is insufficient to encourage a large-scale transition from traditional teaching to blended learning. However, an even more serious limitation is that, despite good initiatives like the TU/e Education Innovation Fund [34], we lack the resources to fully develop the potential of blended learning. Our current implementation of blended learning relies heavily on the traditional education scheme of plenary lectures and problem-solving hours. As a consequence, the demands on lecturer time and lecturing space are not reduced and no new added value is realized in the on-campus activities. Our digital learning environment should be developed in such a way that classical plenary lectures and problem-solving hours are no longer needed, and our limited resources (lecturer time and space) are optimally invested. Examples of the required developments are the online solving of exercises with automated feedback or either real or virtual instructors, a digital assessment system with intelligent automated correction, and a student progress monitoring system. With these and other technical developments we could place the primary learning process (knowledge gathering, basic practice and assessment) in the digital (online) domain and develop scarce and purposeful on-campus activities involving small groups of students that aim to achieve the acquisition of deeper knowledge and rely on teacher/student and peer interaction. For example, one scenario is that students should earn their right to participate in the on-campus activity, or to have access to lecturer time, by satisfactorily completing the required digital modules.

Going back to the larger picture, building an online educational system is an ambitious and costly enterprise that will require strong alliances with other universities worldwide to share and exchange materials and knowledge, and engage in joint educational projects exploiting the full potential of our connected world. In this way we will not only be able to offer our students the best of both online and on-campus worlds but also optimally prepare them for their future in an inter-connected society.

The connection between multi-disciplinarity and diversity

TU/e “Where innovation starts”. Our university has expressed the ambition to be internationally recognized as a university where technological innovation takes place. The CWTS Leiden Ranking ranks our university as No. 1 in research collaboration with industry, and we are taking new steps, such as the Innovation Space and the TU/Eindhoven Engine, to further develop and strengthen our innovative profile.

In this context, the ability to combine knowledge and research results from different disciplines, multi-disciplinary research, is becoming more and more important. In line with this need for increased interaction between disciplines we have expressed the ambition to deliver T-shaped engineers.

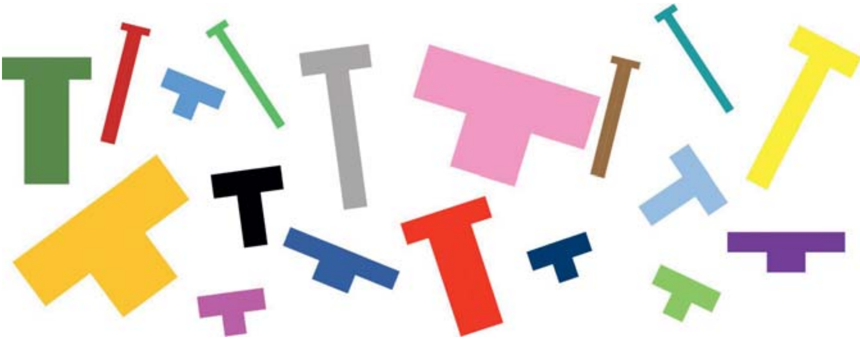

Figure 15
T-shaped engineer.

But what is a T-shaped engineer exactly? How tall should the T be? What is the right balance between the length and the width of the T? How many legs should the T have? Well .... There is no ideal T. In my ideal world we would be able to deliver engineers who are pure specialists, engineers who are pure generalists, and everything in between. A diverse and pluriform collection of T’s. And why? Because diversity is one of the pre-requisites for innovation. Multi-disciplinary, out-of-the-box thinking requires teams whose members have not only different disciplinary knowledge but who also bring different backgrounds and styles. This sounds like stating the obvious, but the issue here is that all these different people should be prepared to embrace this diversity. It is well-known that diverse teams are more creative and innovative than homogeneous teams. However, this comes at a price, because people in homogeneous teams feel they are more effective and feel more confident in their interaction with the other team members. Diversity hurts, it implies a choice and a conscious effort to step out of our comfort zone. This requires not only an individual effort, but also an effort on the part of the organization to encourage and facilitate diversity at all levels.

As I mentioned earlier, our educational ideal is based on personal interaction between master and student, in other words, it is based on educating by example. Therefore, in order to be able to welcome a diverse population of students and deliver engineers who understand and can deal with the challenges of a diverse connected world, our university itself should be a diverse, inclusive community. Unfortunately we have a long way to go to get there.

The lack of diversity in academia applies not in the last place to our research staff, and I am not only talking about gender diversity or ethnicity. The way we measure the performance of our research staff, based on simply counting output: numbers of publications, numbers of citations, number of funded projects, etc., has led to a competitive system with a monochromatic definition of research excellence. The "publish or perish" race, with increasing numbers of publications appearing at a faster and faster pace, inevitably forces specialization in narrower and narrower research fields in order to be able to keep up and produce papers quickly. As a consequence, most researchers work within a narrow research field, visiting the same specialized conferences every year, reading and citing works by a limited number of colleague researchers, and collaborating in project consortia within the same homogeneous network of specialists. This situation reinforces disciplinary boundaries and focuses scientists' attention inwards rather than on the problems of the outside world [35]. In scientometrics work presented by Rafols et al [36] it is concluded that excellence-based journal rankings exhibit a systematic bias in favor of mono-disciplinary research. This bias is likely to have a negative impact on the evaluation and funding resources of groups and organizations doing inter-disciplinary research, discouraging researchers from pursuing interdisciplinary research activities. This is just an example of how our "excellence measurement systems", not only within the university but also, most importantly, at national and European funding agencies, are a serious obstacle to inter- and multi-disciplinary research and, therefore, to innovation. Don't get me wrong, funding schemes like the NWO Vernieuwingsimpuls and EU ERC are crucial to sustain fundamental research, which will eventually lead to innovation. However, by exclusively labeling this kind of research as "excellent" we in fact label everything else (multi-disciplinary research, applied research, user-driven innovation, engagement with society …) as "not excellent", thus mediocre. Is this really what we want?

I do not think so. We need to broaden our scope of what a university researcher should be and build a team of people who together can dive into the deep waters of fundamental research and fly high in the sky to oversee the connections between disciplines, application fields and societal needs, in order to continue to develop our innovation power and create added value for society.

Sound connections in my life

It would be impossible to name all the people who helped the 16 year-old-girl who dreamed of a future in science become the person who is standing here before you today. But I would like to express my gratitude to a number of people who have, in one way or another, assisted me since I moved to the Netherlands more than 16 years ago.

I would like to thank the Dean of Mechanical Engineering, Philip de Goey for supporting my promotion and for the many years of fruitful collaboration.

Furthermore, I would like to express my gratitude to my colleagues at Dynamics and Control and in particular to Henk Nijmeijer, head of our group, for his support and guidance from the day I first joined the group back in 2002.

I am grateful to all my colleagues at MWL, KTH Royal Institute of Technology, and in particular to Leif Kari, Dean of the School of Engineering Science for supporting my professorship at KTH but, above all, for his personal guidance and support, and to Siv Leth for the fantastic collaboration these past years. Tack så mycket Leif och Siv.

None of the research I have discussed today would have been possible without the Post-docs, PhD and MSc students I have had the opportunity to work with through the years. I am extremely grateful to all of them and, in particular, to Rick, René, Francois, Jia, Maarten, Hao, Joris, Elise, Hefeng, Oskar, Afzal, Muttalip, Elias, Hanna, Fredrik, Erik, Igor, Ron, Ruud, Sebastian, Toby and Stijn.

My activities with educational innovation would not have been possible without the support of the educational office and I would particularly like to thank Corinne, Suzanne, Alexandra, Bianca, Esther and Sonia for their support during my educational “experiments” and for the many fruitful discussions.

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Through the years I have met several people who have helped me with their advice and have been (informal) mentors and coaches for me. I am very grateful to Maarten Steinbuch, Herman Beijerinck and Han Meijer for their spot-on advice. I would also like to express my deepest gratitude to Mico Hirschberg for his scientific and personal guidance and to Tineke van den Bosch for her extremely valuable coaching sessions.
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Mikel y Aimar, gracias por vuestra paciencia mientras escribía esta charla inaugural. Tengo suerte de ser vuestra ama.
Ard, ik weet dat het een cliché is, maar “behind every great woman there’s a great man”.

Ik heb gezegd.

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Curriculum Vitae

Prof.dr.ir. Ines Lopez Arteaga was appointed full professor at the Dynamics and Control group of the Mechanical Engineering Department at Eindhoven University of Technology on April 1, 2016.

Ines Lopez Arteaga received her PhD degree in Mechanical Engineering for her work on railway wheel dampers from the University of Navarra (Spain) in 1999. Until 2001 she worked as researcher at Centro de Estudios e Investigaciones Técnicas (CEIT) where she mainly focused on noise and vibration reduction in railway applications. In 2001 she moved to the Netherlands to work at DAF Trucks and later at INNAS BV as noise and vibration specialist. In 2003 she joined the Dynamics and Control group of the Mechanical Engineering Department at Eindhoven University of Technology, where she has established research lines on tire/road interaction, acoustic cameras and material acoustics. From 2011 to 2014 she was visiting professor on Engineering Acoustics at the Marcus Wallenberg Laboratory for Sound and Vibration Research (MWL), KTH Royal Institute of Technology (Sweden), where she was appointed full professor in 2014. At KTH, she was vice-director of the Odqvist Laboratory for Experimental Mechanics (2013-2016) and head of MWL (2016). She is subject editor for the Journal of Sound and Vibration, member of the board of directors of the International Institute of Acoustics and Vibration (2013- 2016) and board member of the Dutch Acoustic Society.

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