Research on Engineering Education; the development of a field of applied research

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Abstract — Higher engineering education has become field of research in its own right. We need evidence and knowledge about the effect of our educational choices. This development towards a more research based approach is sustained by the growth in conferences, journals and publications dedicated to the subject. This paper portrays the development of this research field from the emergence of psychology as a scientific discipline in its own right until the establishment of multidisciplinary international networks focussing on Engineering Education Research.

Index Terms — Psychology, Pedagogy, Engineering Education Research

INTRODUCTION

The ability to pass on knowledge to others is one of the core characteristics of human beings. Human society depends on the transfer of skills to the next generation. Organising this learning process has a long standing tradition. Tradesman would learn their skill in the workshop, often rum by a relative. After a long learning period they could demonstrate their skill by performing a "master piece". Since ancient times, the wealthy and powerful have hired teachers to train their young, preparing them for their future positions. Over time these tutors or pedagogues have developed strategies to deal with their assignment. For a long time however, the main pedagogic approach was based on repetition. The tutor sets an example which is copied by the students in endless practice runs. Even in the years just before the Second World War students in Architecture in Delft were expected to learn how to become architects by copying the work of great masters.

These past years we have been able to observe a boost of research activities aiming to gain scientific knowledge on engineering education. Evidently teaching and learning are examples of human behaviour. As such the quest for knowledge in this field belongs to the domain of the social sciences. In this paper I will present an overview of the development of scientific research in this field, starting with general approaches in pedagogy and psychology.

PEDAGOGICAL AND PSYCHOLOGICAL PERSPECTIVE

Aiming to improve the effectiveness of their efforts teachers of all times proposed a variety of pedagogical methods. In the particular at the end of the 19th and the beginning of the 20th century a multitude of methods directed at the education of young children was proposed by pedagogues like: Maria Montessori, Friedrich Fröbel, Rudolf Steiner, John Dewey, Jerôme Bruner. Pedagogical theories represent an approach to science that aim for effects in practice. At the core of their methods stands an educational philosophy based on assumptions about human nature and in particular the human ability to learn.

Research instigated by such pedagogical approaches is predominantly descriptive in nature. Rather than to compare competing alternatives a typical pedagogic study details the characteristics of one particular method. If the collection of quantitative data is part of the study, usually this takes the form of an evaluation study, searching for corroborating evidence for the method in question.

of psychological research to our understanding of the processes of learning and teaching. In the research tradition of psychology experimental studies are more important. That is to say, this is at least true for the psychologists who deem their profession an empirical science [1]. There are also practitioners of psychology who feel that actions in practice are paramount, just like in the field of pedagogy. In a polemic discussion on the scientific status of psychology the Dutch psychologist Duiker introduced the term "salutair" to designate activities of scientist aiming to promote human well being [2]. Duiker argues that if you want to improve a certain condition you first have to know what it is and how it can be influenced and that therefore if you aim to help people to feel better, psychological research is a necessity. The next section highlights some of the contributions.

PSYCHOLOGICAL THEORIES ON TEACHING AND LEARNING

The origins of psychological research

The early psychologists build on the research traditions of the natural sciences with emphasis on empirical experiments. The establishment of the first psychological laboratory by Wilhelm Wundt in Leipzig in 1879 is generally regarded as the beginning of psychology as a scientific discipline [3] It was not so much that Wundt and his students asked different questions than those of the old philosophers, it was more that different methods were used to find answers to these questions. This was the key feature that set psychology aside as a separate discipline: different methods were used to find answers to these questions [4]. In the second half of the 19th century empirical experiments became an important tool in science. Wilhelm Wundt turned psychology into a scientific discipline in its own right, by applying these methods systematically to human experiences.

Definitions

A first step in psychological research is the definition of the relevant concepts. Before going into research on teaching and learning we first need to agree on what we are looking at. Learning is an activity in its origin. The etymological roots of the word ´learning´ go back to the activity of finding a track [5]. Complementary, the meaning of the word teaching is derived from roots referring to the act of pointing at something or pointing something out as is still clearly evident in many European languages:

- Dutch: onderwijzen
- German unterwissen
- Scandinavian languages unterwisen
- French: ensigner

Also the English word teaching goes back to a Saxon root ´tecam´, with the same connotation. Hence, from ancient times on a teacher is someone who transfers certain knowledge or skills to learning by pointing it out. The teacher explains and demonstrates, enabling the learner to follow in his footsteps.

A broad definition of learning is to acquire new behavioural potential [6]. People learn in all sorts of different ways. Little children learn by mimicking their parents, and they exercise their skills by play. When you read a book, watch a movie, or discuss something with your friends you may learn something new. Evidently, much learning occurs without us noticing it. This marks an important difference between learning and education. Education involves the conscious planning of learning activities. There are goals in terms of desired competencies and there is a programme designed to help students attaining the objectives. Therefore education could be defined as the intentional organization of learning.

Behaviourism

Psychological research on learning started with the discovery of the phenomenon of classical conditioning by Ivan Pavlov early in the 19th century [7]. Pavlov observed that a when a dog was exposed to a stimulus like a light and some food was offered at the same time, the natural response of producing saliva was quickly paired with the external stimulus. Continuing this type of research with other conditions and other animals the American psychologist B.F. Skinner established the school of thought labelled "behaviourism". According to the behaviourists everything organisms do should be regarded as behaviour and it should be investigated based on empirical observations rather than on inferences about thoughts and inner feelings.

Classic learning theories have contributed to the success of technology based instruction. Skinner's introduction of programmed instruction was one of the first attempts to implement behavioural principles in an instructional situation. Principles of behaviourism that have found their way into design of technology based instruction include: positive reinforcement, feedback, errorless learning, use of complex schedules of reinforcement, the importance of strength of associations [8].

Constructivism

The theory of constructivist education puts more emphasis on the content, maintaining that learning is a process of construction and confrontation of meaning rather than exploration and memorization of facts. Constructivism presupposes that it brings an advantage for the students if they acquire knowledge by building it from innate capabilities by solving problems in an organized process and in interaction with the environment [9]. The epistemological theory by Piaget is a developmental model recognizing a fixed order progress through several cognitive stages. Piaget did build his theory on close observations of his own three children. Later the concepts were validated in more extensive quantitative research.

According to the constructivist theory is assumed that the students construct knowledge for themselves by creative activities such as planning and design. Within constructivism two branches are distinguished. Cognitive constructivists give priority to sensory-motor and conceptual activities of individual students [10] and Social constructivists prefer building knowledge by a group of learners in social context [11]. In particular this last version aligns well with the concepts of problem based learning in small groups [12]; [13].

Cognition and neuropsychology

The main problem of empirical research in psychology has always been that it was not possible to observe what someone else was thinking. However, recent trend in neuropsychological research seem to promise a breakthrough in this respect. Technological innovation like Positron emission tomography (PET) scans and Magnetic resonance imaging (MRI) scans make it possible to see what part of the brain are active and consequently to identify what part of the brain is responsible for processing certain information [14]; [15]. At the moment it is still difficult to assess the impact of these investigations on the actual learning and teaching in the classroom. Nevertheless, the potential is enormous as can be seen for instance from the fact that it has been possible see the limits of free will. In an experimental set up it has been demonstrated that the brain starts to respond before a conscious decision to do so could have been made [16]. Even if actual mind reading may still be far away in the future it could very well be possible to verify the level of knowledge of a particular topic by analyzing brain activity.

RESEARCH AND DEVELOPMENT IN HIGHER EDUCATION

Evidently there is a gap between specialized research in psychology and the application of relevant knowledge in practice. The next section will focus on the application in the field of higher engineering education.

During the sixties of the last century the number of students enrolling in higher education increased dramatically. As a consequence, universities had to adjust their teaching methods in order to deal with mass higher education [17]. Innovation and improvement soon became keywords in dealing with this issue. Universities in most countries in the north-west of Europe established their own Center for Educational Research and Development. In this paper the emergence of such centers in the Netherlands will serve as an example.

It would seem natural in a scientific environment that research plays a major part in the establishment of a solid foundation for quality improvement. As it was put by a reporter at the end of the first national convention on Research of Higher Education in the Netherlands Eindhoven 27-28 April 1966 [18]: *"If one wants to improve the quality of teaching in higher education, than, before all it is necessary to establish contact between the following two groups of people: those who are concerned with the teaching of science and those who are engaged with the science of teaching"*

At the beginning of the increase in interest for research on higher education, the Dutch schools of Technology played a central part. The third national convention on Research of Higher Education was organized in Delft, January 15-16 1976 [19]. At the opening of this conference the minister of higher education addresses the position of the RWO [Research of Higher Education] centers [20]. The minister points out that the position of the RWO institutes differs markedly from that of other research institutes, because there finances are drawn directly from the university funds. Although the financial position of the RWO institutes is sound; the positioning of these institutes into the university organization is difficult. The gap between research and application of the outcomes is one of the problems singled out by the minister. Since the average University professor does not have enough time to study educational science next to his own profession, the minister states, it is not surprising that it is hard to implement new educational insights in the practice of higher education.

The various educational centers joined forces in an informal network of Centers for Research on Higher Education. The network includes both general universities as well as Universities of Technology. The CRWO network continued to organize study conferences [21]. Also a section Higher Education was established as a thematic group operating within the national framework of educational researchers. By the time of the fourth national convention on research in Higher Education in 1981 research institutes were established at or in close relation to most Universities. Although some of these institutes were strictly service oriented (notably the educational service at TU Delft), most were research departments with their own scientific staff, fitting to the trend in industry of establishing 'Research and Development Centers'.

Despite initial optimism, the problem of a deficient connection between research outcomes and educational practice in higher education became bigger and bigger. In part because the researchers tended to become more and more involved in their own theories, in part because the teachers did not apply the same sound scientific methods they used for their own professional field to their teaching tasks [22]. A logical consequence of this gap was a growing pressure on the RWO institutes from their financers to spend less time on scientific research and invest more in innovation projects with a concrete and measurable outcome. Gradually the institutes drifted apart. Some institutes even adapted to the style of commercial consultancy firms and managed to continue the growth process. Others turned into research institutes drawing on research funds, the ones who were more dependent on the primary stream of university funding tended to lean more heavily on consultancy and training. In some cases the research-oriented department were curtailed and re-

positioned within the universities administrative staff. An example of this development is Rotterdam, were the Erasmus University closed down her department of educational research completely. A few years later a new institute was founded, focusing on consultancy and staff development rather than on research.

Until recently the CRWO continued to organize annual study conferences, in recent years focusing on the role of the educational consultant rather than on research. Early this year the CRWO dropped the research in its name completely, changing into the society for consultants in higher education (EHON).

ENGINEERING EDUCATION RESEARCH

The employees of the educational centres above were mainly of social scientist. This has resulted in a notable gap between the professors in higher education and the consultants. Those who are concerned with the teaching of science and those who are engaged with the science of teaching have been at odds. More recently there has been a trend to involve the teachers in a discipline in the research on teaching in their field. In many cases this takes place as collaboration between experts in the field and social sciences research experts.

The past years have witnessed the development of engineering education research into a field of scholarly research in its own right. This development towards a more research based approach is sustained by the growth in conferences, journals and publications dedicated to the subject. Engineering education research in Europe, is characterized by a unique interdisciplinary approach. Presently, engineering education researchers do have various backgrounds in engineering, science, social science and educational psychology investigating higher engineering education.

Recognizing the importance of this emerging field of applied research the European Society for Engineering Education (SEFI) established in 2008 a Working Group on Engineering Education Research. The objective of this working group is to create a European community of engineering education researchers in order to contribute with research evidence to the advancement of engineering education.

Almost in the same time frame a new international network organisation has come into view. Research in Engineering Education Network (REEN) grew out of REES (Research in Engineering Education Symposium) and was established to address the need for an international forum for scholars interested in discussing and advancing research in engineering education. The first REES meeting was supported by a National Science Foundation grant and was held in 2007 in Hawaii. This was followed by two subsequent meetings in Davos in 2008 and in Cairns in 2009. The intention is for the network to become increasingly inclusive of all dimensions of Engineering Education research. REEN aims to join the growing international community of engineering education researchers, based on a vision that essential innovations in engineering education need to be founded in research. In developing the best Engineering Education for the engineers of tomorrow, researchers across the globe will provide evidence that influences both institutional and governmental policy.

The REEN Mission welcomes all who may have an interest in this field:

'To provide an independent, international and inclusive forum to advance scholarly discourse on research in engineering education'

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