Bachelorthesis
Nr. 1
The influence of hands-on learning on the learning process of engineering students and its application at Stanford University and Technical University of Munich
Jan Behrenbeck

I hereby declare that the work presented in this thesis is entirely my own and that I did not use any sources or auxiliary means other than those referenced.
Bachelorthesis
Nr. 1

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Topic: Application of Hands-On Learning in the University Context

Motivation:

Germany’s economic strength and thus its prosperity is based on a strong industry with a high innovation potential. Especially the small and medium businesses and Start-Ups are responsible for those innovations and guarantee Germany’s position in the world wide competition. The critical factor to ensure its preservation in the face of the demographic change is the education of highly skilled engineers. To drive innovation and solve problems in a world more complex than ever in history, young engineers graduating from universities all over the country must not only have comprehensive knowledge. They need to have the ability to apply their knowledge to complex problems, to be creative to find new ways in a confusing environment, to work in interdisciplinary teams and cope with unpredictable circumstances. (HAMPE, 2012; MERKEL & SATTELBERGER, 2008).

At the present time the education of engineers in Germany in technical universities within the elementary studies has a strong focus on the impartation of academic contents. According to HAMPE (2012) students in their first years do not understand the connection between and thus the practical meaning of different academic subjects, they get overchallenged and fail their exams. As a result, they lose motivation and a study of Hochschul-Informations-System (HIS) revealed that only every second beginner is able to complete his or her degree (HEUBLEIN, RICHTER, SCHMELZER, & SOMMER, 2012, p. 17). Furthermore, when students graduate from university, a number of them do not know how to apply their knowledge because they do not have enough practical experience. This can decrease the employability of graduated engineers on the market and lead to a lack of professionals, which is dangerous for the national economy (MERKEL & SATTELBERGER, 2008; RAUEN, FELLER, & RÖGER, 2009; SONNABEND, 2014).

Consequently, the task for the next years is to motivate students to decrease the university dropout rate and to improve the current education of engineering students regarding their ability of applying academic knowledge to raise innovative professionals (MERKEL & SATTELBERGER, 2008).
There are a number of approaches to solve this problem. One approach is the instructional method Hands-On Learning, which focuses on the practical application of academic theories and concepts and the interaction with physical objects. To evaluate, if this method is reasonable regarding the presented problem, its effect on the learning process of engineering students has to be analyzed.

**Goals:**

The goal of this work is on the one hand to reveal a number of basic factors that influence the learning process in the human brain, to review the hands-on learning approach theoretically based on these findings, and to detect the influence of hands-on learning on the learning process of engineering students.

On the other hand this work collects experiences, which have been made applying the method in a university context at Stanford University and Technical University of Munich, and analyzes one course in detail from each university regarding the use of hands-on learning and its effect on the students to obtain critical factors for the design of hands-on course elements.

**This results in the following content:**

- **Scientific analysis of learning in the human brain**
  - Neuroscientific analysis of the learning process and information memory in the human brain
  - Derivation of influences on this process and deduction of requirements for a beneficial learning environment
  - Definition and review of the instructional method Hands-On Learning based on the deduced requirements

- **Empirical analysis of Hands-On Learning in the university context**
  - Collection of examples for the application of the hands-on approach at Stanford University and Technical University of Munich
  - Summary of experiences and lessons learned by professors and experts from Stanford University and Technical University of Munich
  - Analysis of two university courses in detail regarding their use of hands-on learning and its effect on the student learning process and overall experience
    - ENGR14: Introduction to Solid Mechanics, Stanford University
    - GEP: Grundlagen der Entwicklung und Produktion, TUM

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Garching,
THE INFLUENCE OF HANDS-ON LEARNING ON THE LEARNING PROCESS OF ENGINEERING STUDENTS AND ITS APPLICATION AT STANFORD UNIVERSITY AND TECHNICAL UNIVERSITY OF MUNICH

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1 Introduction

Germany’s economic strength and thus its prosperity is based on a strong industry with a high innovation potential. Especially the small and medium businesses and Start-Ups are responsible for those innovations and guarantee Germany’s position in the world wide competition. The critical factor to ensure its preservation in the face of the demographic change is the education of highly skilled engineers. To drive innovation and solve problems in a world more complex than ever in history, young engineers graduating from universities all over the country must not only have comprehensive knowledge. They need to have the ability to apply their knowledge to complex problems, to be creative to find new ways in a confusing environment, to work in interdisciplinary teams and cope with unpredictable circumstances. (HAMPE, 2012; MERKEL & SATTELBERGER, 2008).

1.1 Motivation

At the present time the education of engineers in Germany in technical universities within the elementary studies has a strong focus on the impartation of academic contents. According to HAMPE (2012) students in their first years do not understand the connection between and thus the practical meaning of different academic subjects, they get overchallenged and fail their exams. As a result, they lose motivation and a study of Hochschul-Informations-System (HIS) revealed that only every second beginner is able to complete his or her degree (HEUBLEIN, RICHTER, SCHMELZER, & SOMMER, 2012, p. 17). Furthermore, when students graduate from university, a number of them do not know how to apply their knowledge because they do not have enough practical experience. This can decrease the employability of graduated engineers on the market and lead to a lack of professionals, which is dangerous for the national economy (MERKEL & SATTELBERGER, 2008; RAUEN, FELLER, & RÖGER, 2009; SONNABEND, 2014).

Consequently, the task for the next years is to motivate students to decrease the university dropout rate and to improve the current education of engineering students regarding their ability of applying academic knowledge to raise innovative professionals (MERKEL & SATTELBERGER, 2008).

1.2 Goals

In November 2013 Prof. Dr. Hampe from the Technical University of Darmstadt was rewarded with the Ars-legendi award of ‘Stifterverband der deutschen Wissenschaft’ for his innovative and specifically fitted teaching concept for the early stage studies named KIVA (= ‘Kompetenzentwicklung durch interdisziplinäre Vernetzung von Anfang an’). In this concept all students have to participate in a one-week interdisciplinary real world project in the very first week of their studies. According to HAMPE (2012) this project did not only motivate the students for their but also decreased the dropout rate to only 20 percent

The instructional method that HAMPE applies in KIVA is called Problem-Based Learning (PBL) approach. In this method students get together in teams to learn through facilitated but still complex problem solving. During this process the students have to engage in self-directed learning (SDL), which means identifying missing knowledge, acquiring the knowledge and applying it to the problem. The role of the responsible teaching staff changes from a knowledge presenter to a supervising mediator (HMELO-SILVER, 2004).

TU Darmstadt is not the only university to rely on this instructional method. There are other institutions all over the world such as Maastricht University, Arizona State University, Olin College of Engineering Boston or Stanford University that make use of this learning approach by (re-) organizing their course concepts in a problem-centered way and diminishing the use of the traditional teacher-centered approach. And a number of them go even further by using the hands-on approach on learning. Hands-On Learning (HOL) is an instructional method that extends PBL by adding and narrowing on the physical interaction with real objects (a detailed definition follows in section 2.3.1).

The Chinese politician and philosopher Confucius, who lived in the fifth century before Christ, once said: “I HEAR AND I FORGET. I SEE AND I REMEMBER. I DO AND I UNDERSTAND.” Querying this quote leads to the fundamental question, which influence hands-on experiences have in particular on the learning process of engineering students especially in contrast to the effects of project-based learning. Answering this question means to evaluate if physical interaction and activity support engineering thinking and understanding, help students acquire academic knowledge and cause an increase in engineering practice skills.

This thesis reveals a number of basic factors that influence the underlying learning process in the human brain, collects experiences that have been made applying the hands-on approach at Stanford University and Technical University of Munich, and analyzes one course in detail from each university regarding the use of hands-on learning and its effect on the students.

1.3 Content

This thesis consists of two main parts to provide both a scientific base and an empirical analysis:

Part one is a scientific analysis of the influence of hands-on learning on the learning process of engineering students. Hands-On Learning (HOL) is an instructional method that is characterized by the physical interaction with real objects (a detailed definition follows in section 2.3.1). For that, firstly the neurological mechanism of learning in the human brain is explained. Secondly the influences that affect this process are deduced and requirements for a beneficial learning environment are established. Lastly there is a review of the hands-on approach on learning to check, if this method meets the deduced requirements.

The second part contains different examples for the implementation of hands-on learning into university courses and a collection of experiences and lessons learned from Stanford University and Technical University of Munich. Moreover there is a detailed analysis of two
specific courses regarding their use of HOL and its effect on the students: The first one is an engineering fundamentals course on solid mechanics from Stanford University (CA, USA) in which different hands-on elements can be found. The second one is a project-based fundamental class on product development for mechanical engineering students at the Technical University of Munich (BY, Germany). Finally, recommendations for the improvement of those courses are deduced based on the findings about the learning process in the human brain, the lessons learned at Stanford University and TUM and the individual experiences in each course.
2 Scientific Analysis of Learning

The human being as living creature is a result of evolution. Thus when reasonable educational concepts are developed, there has to be taken a close look at the mechanism of learning in the human brain. Modern technologies allow the observation of processes and structures on a cellular and molecular scale. Knowing how the human brain works, helps to deduce requirements for a beneficial learning environment and eventually to improve the educational system.

Therefore this chapter provides a neuroscientific analysis of the basic structure and functionality of the human brain with a focus on the learning process. Based on that, influences on this process and requirements for a beneficial learning environment are deduced. Finally there is a definition and review of the hands-on approach on learning by means of the established requirements.

2.1 The Learning Process in the Human Brain

Humans see with their eyes. They hear with their ears. They smell with their nose. They taste with their tongue. They sense with their skin. Those five sensory organs contain the sensors of the human body. In the brain all the information is processed, evaluated and stored.

On an abstract level in the sensory organs analogue information from the environment is converted by biosensors into digital signals. For example the electromagnetic waves of light (so called photons) are converted by the cells of the retina (so called photoreceptors) into a sequence of electrical impulses, which corresponds to an array of zeros and ones (impulse = 1, no impulse = 0). Each impulse has the same amplitude. The sequence encodes the information. Those impulse sequences are the input to the brain. The brain processes this input information and eventually puts out another digital signal, which is carried to muscles and glands (SILBERNAGL, KLINKE, & PAPE, 2005, p. 67f; SPITZER, 2002, pp. 41-49).

The next section is an explanation of this mechanism on a cellular and molecular level.

2.1.1 The Structure and Basic Functionality of the Human Brain

The human brain, the learning organ, can be divided into four parts: The cerebrum, the cerebellum, the interbrain and the brainstem. The part that is responsible for cognitive thinking and learning is the cerebrum or to be precise the cerebral cortex (ADEAR, 2008, pp. 10-11). The whole nervous system consists of nerve cells, so called neurons, which all work the same as they transport information. In average the human brain has 21 billion neurons, which do already exist after birth (SPITZER, 2002, p. 51).

Each neuron can be divided into three parts: The dendrites and the cell body where information in the form of impulses is received, the axon along which the information is
transported, and the presynaptic knobs where information gets dropped (there are thousands of synaptic knobs per neuron). On a molecular level, inside and outside the neurons there are a lot of different ions, both cations (positively charged ions) and anions (negatively charged ions). Those ions that are mainly responsible for the brain processes are potassium (K\(^+\)), sodium (Na\(^+\)) and calcium ions (Ca\(^{2+}\)). The inside of the neuron is connected to the outside by selective permeable protein channels. The selectivity of the channels towards different ions and the electrical attraction and repulsion of unlike and like charged ions create a gradient of overall charges at the membrane of the neuron. This membrane potential is called **resting potential** and quantifies to about -70mV (SILBERNAGL ET AL., 2005, PP. 64-66).

![Figure 2-2-1: Ionic Basis of the Resting Membrane Potential (JAYNA, 2012)](image)

All neurons inside the brain form a huge network as they are internally connected to each other by **synapses**. Furthermore, there are several nerve fibers into and out of the brain that transport the input and the output information. For every connection from the brain to its environment there are 10 million synapses within the brain where information is processed. One single neuron can be connected to up to 10,000 other neurons only as a recipient. Each synapse involves two neurons: The **presynaptic neuron** and the **postsynaptic neuron**. The space between the presynaptic knob and the membrane of the postsynaptic neuron is called **synaptic cleft**. At a chemical synapse\(^1\) impulses are transferred with the help of small particles called **neurotransmitters**. They are stored in small spheres called vesicles in the presynaptic knob. When an electrical impulse reaches the synaptic knob some cation channels open and the incoming calcium ions force vesicles to fuse with the presynaptic membrane and thus release the transmitters into the synaptic cleft. The neurotransmitters diffuse to the postsynaptic membrane where specific receptor proteins (AMPA receptors)

\(^{1}\) In the following I focus on the mechanism of chemical synapses. There are also electrical synapses but their number is very small and they do barely exist in the human brain, because they have the disadvantage of not being able to assess incoming information.
are implemented. Those receptors are ion-channels permeable for potassium and sodium which open as soon as a neurotransmitter binds to them. When those receptors are activated, $K^+$ and $Na^+$ can flow into the cytoplasm, which depolarizes the membrane for a short moment. At this point the all-or-none law holds. If there are enough neurotransmitters to open a sufficient number of channels and the depolarization crosses a specific threshold value, the postsynaptic membrane potential locally rises up to $+30\text{mV}$. This temporary alternation of charge is also called spike or **action potential (AP)**. Before the cell manages to get back to its rest potential that change in polarization is transferred similarly to in a domino-reaction through the cell along the axon to the following synapses where the mechanism starts all over again. If the concentration of neurotransmitters in the synaptic cleft or the number of receptors is insufficient, there will be no AP and thus the impulse will not be transferred to the next neuron (SILBERNAGL ET AL., 2005, PP. 67-69; SPITZER, 2002, PP. 41-44).

For one thing the amount of available neurotransmitters, the number of receptors and thus the impulse transport is dependent on the individual strength, size or sensitivity of the synapse. For another thing it depends on the rate of incoming APs at the synapse as this frequency encodes the intensity of a signal. And since the presynaptic knob needs the so called recreation time to get back to the resting potential as it has to restore the equilibrium, consecutive action potentials can add up their effects. More calcium ions get into the knob and force a higher number of vesicles to release their neurotransmitters into the synaptic cleft. This increase in concentration can last to activate the postsynaptic neuron where a single impulse would not be strong enough. Likewise one postsynaptic neuron can be activated if two or more preceding neurons are activated simultaneously and there depolarizational effects superpose.\(^2\)

To sum up, while all neurons have the same mechanism as they are simply forwarding a unitary impulse from one synapse to another – you could compare them to wires on a circuit

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\(^2\) Of course there are a lot of chemical effects caused by endogenous substances called neuromodulators or drugs but this is not relevant for our considerations why I narrow on the basic principles.
board, the synapses serve as ‘intelligent’ elements in the brain. Their function is to assess incoming impulses from different presynaptic neurons and to induce follow-up APs – similar to voltage-dependent transistors, which leads to an input-specific activation of neuronal areas in the brain (SILBERNAGL ET AL., 2005, PP. 80-85; SPITZER, 2002, PP. 41-50).

Figure 2-3: Impulse transport at a chemical synapse between the presynaptic and the postsynaptic neuron (DOCCHECK, 2014)

2.1.2 The Storage of Knowledge and Learning in the Human Brain

To understand the concept of knowledge it is necessary to know how memories and explicit relations are stored in the human brain. There is one underlying rule: The brain is modular and every neuron is the representation of a fraction of the real world. This means that one piece of information is not processed in the whole brain but that there are modules or areas for specific topics. For example there are neurons or neuronal areas for colors, faces and shapes but also for rules, values, speech and relations (SPITZER, 2002, PP. 12-14; 2009A). Thus when a neuron is activated by any kind of input, it represents this input-related piece of the real world.

For example, if one sees a green leaf, the photoreceptors in his or her eyes (sensors) convert this analogue information into a digital signal. This signal is transported by several neurons and synapses into the brain. In the brain the complex system of interconnected neurons and synapses with different strengths ensures that some neuronal areas are activated and some are not. Those neurons that are activated are the representation of the specific input, in this
case the color green and the shape leaf.\textsuperscript{3} This mechanism is the same for rules and relations and everything that is represented in the brain. Scientists call this imaging of the real world \textbf{neuronal representation} (Spitzer, 2002, pp. 44-50). The primary cortical areas are responsible for the representation of things such as vision, hearing and the execution of motions. The multimodal association cortex instead is responsible for abstract things such as the meaning of words\textsuperscript{4} (Spitzer, 2009B).

Consequently the entirety of all connections (synapses) and representations (neuronal areas) in the brain is what people call their personal knowledge. Learning, however, is nothing but the change of knowledge and thus the modification, creation and degeneration of neuronal representation and linking (Spitzer, 2002, p. 12). Knowing the function and functional mechanism of synapses and the role of neurons as images of the real world, it can be deduced, that learning is nothing but the change of synaptic interconnection. This can happen either by altering the synaptic strength/sensitivity or by creating and erasing whole synapses. Changing the strength of synapses and thus the network alters the activational pattern which leads to a different response of the brain to a specific input signal. A different response means a different representation and a different representation means a change in knowledge: Learning (Silbernagl et al., 2005, p. 818f).

The synaptic strengthening and thus the learning process is scientifically called \textbf{long-term potentiation (LTP)}\textsuperscript{5}. No matter what people do, their brains always learn from experiences and change the neuronal connections accordingly. This process happens very slowly (Spitzer, 2002, p. 11). What makes the synapses change is solely the use of the brain and thus the activation of neurons. For one thing a LTP at a synapse can be initiated by a high frequency input sequence at the presynapse. This feature is called input-specificity. For another thing it can be induced by the high frequency activation of an adjacent synapse that

\textsuperscript{3} This example is very simply and abstract. It shall only give a tangible idea of the basic concept of neuronal representation and knowledge.

\textsuperscript{4} I already want to state at this point that the areas where specific knowledge is saved is dependent on the learning method, of which more later.

\textsuperscript{5} There are also mechanisms of temporary synaptic strengthening (facilitation) and depression. They cause a change in vesicle mobility in the presynaptic knob. but as they are not relevant for long term educational goals I do not consider them in my explanation. For a detailed explanation see Silbernagl et al., 2005, p. 819.
is activated simultaneously. That is called associativity or associative learning.

On a molecular scale the process of LTP can be divided into a first step that includes the induction and early phase and a second step that includes the late phase and persistence of LTP. In the induction phase a lot of neurotransmitters are released in the synaptic cleft. This outstanding high concentration activates a new receptor (NMDA receptor) in the postsynaptic membrane which is blocked under usual concentrations. This receptor ion-channel does not only let pass $K^+$ and $Na^+$ but also $Ca^{2+}$. In the early stage LTP a high concentration of $Ca^{2+}$ in the postsynaptic dendrite starts a chain reaction that activates inactive AMDA-receptors which increase the sensitivity of the postsynaptic membrane. Furthermore, it activates a messenger that diffuses to the presynaptic knob and unleashes inactive vesicles to increase the availability of neurotransmitters. In the late phase of LTP an increase of $Ca^{2+}$ in the dendrites causes a gene expression that can induce the generation of new AMDA-receptor proteins as well as the neoformation of synapses. All those mechanisms lead to a strengthening of synaptic linking caused by high frequency activation.

![Image of neuroplasticity](image)

*Figure 2-5: Neuroplasticity: The Development from a hair branch (above) to a dendritic spine (below) (MAX-PLANCK-INSTITUT, 2007)*

If two neurons are activated randomly without any correlation for a long time, the synapse gets weaker and weaker and in the end it is possible that the neurons segregate. This entire process of changing synapses is called **neuroplasticity** or simply learning (Kandel, 2003; Silbernagl et al., 2005, pp. 818-821; Spitzer, 2002, pp. 75, 94-96, 105-108).

Summing up, as a consequence of neuronal activation synaptic interconnections can change. This change is called neuroplasticity and it leads to a different response of the brain towards specific inputs. The sum of neuronal representations is nothing but a person’s knowledge. Consequently learning is simply the modification of synapses.

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6 There are several substances that can influence this process such as dopamine, of which more later.
7 This reverse process is called long-term depression (LTD) but its mechanism is very similar why I will not explain it here. For a detailed explanation see Silbernagl et al., 2005, pp. 818-822.
2.2 Influences on the Learning Process and Requirements for a Beneficial Learning Environment

The basic neuronal mechanism of LTP/learning is always the same but there are several influence factors that affect this process. The following list of those factors is based on a publication from CAINE & CAINE (2008) and complemented by the declared sources.

1. The cortical representation of information is defined by the way how the content is being learned. For example, if students watch an animation (even if it is interactive) of a control gearbox on the computer this knowledge is stored differently compared to when they crank a lever with their own hands and see the gears turn in real life. This principle is called “Do-Effect”. On a cellular level that means if people involve multiple senses or their whole body into learning they increase the processing depth in their brains as more neurological areas are activated. This activation initiates LTP. Consequently addressing multiple senses and involving the body into the learning process is the first learning enhancing factor (Spitzer, 2009b).

2. A number of studies have shown that focused attention increases the activation in the corresponding representational neuronal areas. That is because attention forces the brain to apply a higher portion of a person’s consciousness on the current learning subject. Unfortunately the 10-minute rule exists, which says that lecturers have to do something emotionally relevant at each 10-minute mark to regain the listeners attention (MEDINA, 2013). Thus creating surroundings that narrow attention and foster concentration is requirement number two for a beneficial learning environment (SPITZER, 2002, P. 151).

3. Factor number three is emotion. Strong emotions trigger the release of a number of hormones and special neurotransmitters such as serotonin or dopamine. It was experimentally verified that those substances play a critical role in LTP as they initiate the late phase (ROSSATE, BEVILAQUA, IZQUIERDO, MEDINA, & CAMMAROTA, 2009). In general, the more emotionally excited humans are, regardless of whether positively or negatively, the better they learn because more transmitters are set free and initiate LTP. Examples for negative excitations are a child touching a hot cook top or memories of September 11th 2001. The child will remember that a cook top can be hot and will not touch it again. And every adult will remember the moment when he or she first saw the video of the burning towers as there was a strong emotion connected to that moment. Regarding the long-term effects negative emotions such as fear and anger cause chronic stress. Consequently creating negative emotions by intimidating students or telling them what they are not able to do is not an appropriate possibility to improve learning in the educational setting. In contrast positive emotions such as happiness do not only support learning by initiating LTP. If dopamine is released by a positive emotion it also activates the endogenous reward system and has a euphoric effect which strengthens the intrinsic motivation. In fact without the activation of the endogenous reward system learning does not take place at all. As a result, creating positive emotions is inalienable for a successful learning experience (SCHULZE, 2006; SPITZER, 2002, PP. 157-164, 177, 184).
4. Human beings have their own endogenous motivational system. It is in the nature that students are generally intrinsically motivated and curious. Nevertheless motivation is an important factor as it is affected by external factors. There are surroundings that enhance students to experience positive emotions and stay engaged, or surroundings that destroy the innate motivation and block the endogenous rewarding. As a result, if teachers desist demotivation and evoke positive emotions by for example fostering the students’ strengths, those are automatically motivated to work on their weaknesses and engage in learning (Spitzer, 2002, pp. 192-195).

The second part of the list consists out of aspects that do not have a special individual influence on the learning process in the human brain but lead to one of the first four factors.

5. The brain/mind is social. Collaborative acting is the best reinforcer for learning because talking with other people about own ideas makes people think about their thoughts. This ability is called metacognitive learning. Furthermore, it comes along with social acknowledgement, solidarity and social security. As human beings are social creatures those feelings are important to their emotional setting. Consequently teachers should emphasize social interaction and show the students that they care about them (Chatfield, 2010; Spitzer, 2002, p. 181).

6. Another way how to evoke positive emotions and narrow students’ attention is to let them work on their personal ideas and interests. The search for meaning is innate and humans like to know a reason for why they do what they do. One possibility to deliver this reason is to make them work in their own interest or on their own ideas. For one thing students are willing to focus and spend more energy on a project that they personally support. For another thing being eventually able to say ‘I have done that!’ , ‘This was my idea!’ or ‘I have personally promoted that!’ gives the students a strong positive feeling of confidence and fulfillment. And eventually it helps students to be creative and apply their knowledge. To sum up, teachers should try to let students work on their own ideas or in their own interests (Spitzer, 2002, pp. 35, 198).

7. Complex learning is enhanced by challenge and inhibited by threat associated with helplessness and/or fatigue. The psychologist Mihaly Csikszentmihalyi established a specific mental state that he called ‘flow’. Flow occurs when students are challenged with tasks that perfectly fit their individual skills; they are neither unchallenged nor overchallenged. People who experience this state of mind start working just for the tasks sake and can forget about time, themselves and their surroundings. Their entire concentration is focused on the task. There are no worries and the perfect relation between difficulty and competence creates intense attention, positive emotions as that kind of work is intellectually satisfying and thus intrinsic motivation. This state is both neuroscientific and psychological seen as the perfect mental state for learning (Spitzer, 2013).
8. “CONTEXT IS RELATED TO FACTS AS THE SKELETON TO THE HUMAN BODY” (SPITZER, 2002, p. 35). Only by integrating specific contentual parts into a superior context, students really understand the content and its meaning and relevance in the superior framework. Having the AHA-moment, realizing why they learn something and what they can do with that knowledge creates positive emotions. Not to know what isolated topics, that students are supposed to learn in lectures and exercises, are good for, causes frustration and evokes negative emotions. Only context makes details interesting. Therefore the use of many and good examples is recommendable (BECK, 2003, p. 3).

Summing up, based on these eight factors, that influence the neuronal learning process, the following list of eight requirements for a beneficial learning environment emerges. This list can be used for course design or for reviewing instructional methods.

1. Addressing multiple senses and involving the body
2. Creating surroundings that foster attention and concentration
3. Creating positive emotions
4. Desisting demotivation
5. Emphasizing social interaction
6. Letting students work on their own ideas and in their own interests
7. Challenging students, creating flow
8. Integrating academic content into a superior context

2.3 Analysis of Hands-On Learning

Based on the knowledge about the neuronal mechanism of learning in the human brain and the deduced influence factors and requirements it is possible to analyze instructional methods regarding their efficacy in theory. To check if an approach meets the requirements it is necessary to refer to a clear definition.
2.3.1 Definition

According to J. G. Brodie, fifth and sixth grade teacher at the East Side Elementary in Edinburgh, “HANDS-ON LEARNING IS LEARNING BY DOING” (HAURY & RILLERO, 1994, P. 14). James Rutherford, director of the science reform initiative, defined in 1993 more specifically:

"HANDS-ON QUITE LITERALLY MEANS HAVING STUDENTS 'MANIPULATE' THE THINGS THEY ARE STUDYING (…) AND 'HANDLE' SCIENTIFIC INSTRUMENTS (…). IN A MORE GENERAL SENSE, IT SEEMS TO MEAN LEARNING BY EXPERIENCE" (HAURY & RILLERO, 1994, P. 16).

This definition supports the theory from section 1.2 that hands-on learning is simply a special manifestation of problem-based learning with a restriction to concepts which involve interaction with physical objects and activities where students have to use their hands and all senses. Regarding this interaction three levels of hands-on learning can be distinguished:

1. Touch and observe,
2. Handle and work,
3. Design and build.

The choice of level and thus interactive intensity has to be made individually by the course designer for every implementation of this approach considering the pursued goals of a course and the surrounding circumstances. Furthermore, in the university context hands-on learning is always connected to an impartation of academic knowledge.

In this work, considering all those aspects, hands-on learning is defined as follows:

Hands-on learning (HOL) in the university context is an instructional method in which students learn through practically applying their academic knowledge to a problem by interacting with a physical object. In HOL, student learning centers on a complex problem that does not have a single correct answer. Students work in collaborative groups or alone while a professor or assistant acts as a facilitator. The level of interaction with the object can be defined by touching and observing an unknown object and recognizing the theory, by handling and working with the object and using the theory or by designing and building the object and applying the theory using one’s own ideas.

Whenever in this thesis the term hands-on learning or HOL appears, it refers to this definition.

---

8 As I am narrowing on (mechanical) engineering students some examples for those objects are natural objects such as metals or liquids, machines or single parts such as combustion engines or gears, tools or physical prototypes (including first stage design prototypes out of paper and carton as well as highly developed functional prototypes).
2.3.2 Review

“Living creatures learn best when they get active themselves. Just watching and listening is not sufficient: We have to create an active dialogue with our environment, if we really want to learn.” (Beck, 2003, p. 5)

Understanding the learning mechanism in the human brain and being aware of key factors that influence this process provides requirements for a beneficial learning environment and thus the basis for a review of the hands-on learning approach.

In the following the established definition of HOL is dissected into three parts. Each part is analyzed by means of the deduced requirements. Evaluating, if the requirements are fulfilled, leads to a theoretical neuroscientific and psychological assessment of the instructional method.

1.) Hands-on learning (HOL) in the university context is an instructional method in which students learn through practically applying their academic knowledge to a problem by interacting with a physical object. In HOL, student learning centers on a complex problem that does not have a single correct answer. […]

Applying knowledge means to link particular theoretical principles from different fields, that students learn from literature or in lectures, to solve a specific problem. In contrast to theoretical application, where students often have to focus on one particular isolated aspect, in practical application students have to drop all assumptions and work on the real world. In their problem solving process they have to consider all disturbances that can occur, which is more complex but also gives them a feeling for reality and strengthens their engineering mindset (HmeLO-SiLver, 2004). This connection to the real world gets supported by working on a physical object. Regardless of whether the task is fictional or real, the closeness to reality and the linking of different fields integrate academic content into a superior context and thus provide a meaning for the students. Furthermore, having different correct answers helps students to be creative and think ‘out of the box’.

2.) […] Students work in collaborative groups or alone while a professor or assistant acts as a facilitator. […]

Oftentimes hands-on learning is realized in project-based courses where students work in interdisciplinary teams. Acting in a social environment supports the learning process. It also provides experience in team work and makes the students handle all the non-technical problems regarding team dynamics. Moreover seeing the teacher as a facilitator and deciding on their own what to do makes them feel self-determining and think to work in their own interests (HmeLO-SiLver, 2004). At last, by working independently or in small groups on their own projects, students can individually fit the challenge level and learning speed to their own skill level and help each other to overcome individual problems easier than in a big classroom. That helps them to set their mind to flow.

3. […] The level of interaction with the object can be defined by touching and observing an unknown object and recognizing the
theory, by handling and working with the object and using the theory or by designing and building the object and applying the theory using one’s own ideas.

Whereas in traditional lectures and tutorials students usually only involve their visual and additive senses, in a hands-on learning they involve by definition their whole body. The degree of interaction, the number of senses and thus the learning enhancement factor is dependent on the applied level of hands-on learning (Level 1: Touch and observe; Level 2: Handle and work; Level 3: Design and build). And those sensory signals do not only increase the neuronal activation. Special odors, noises or other perceptions also evoke individual emotions (HAMPE, 2012; SPITZER, 2009B).

To cap it all, this approach on learning has one further characteristic: It creates an atmosphere and framework conditions (e.g. working in a team or with imperfect resources) that are similar to the conditions in a professional life in the working world.

![Figure 2-7: The role of practical experience in the educational process (LETKEMAN, 2014)](image)

Concluding this chapter, I want to recall the fact that the way how information is stored in the brain is correlated to the way how learning takes place (SPITZER, 2009B). The review on the basis of the definition shows that HOL can fulfill, depending on the specific implementation, every single requirement that has been deduced in section 2.2 for a beneficial learning environment and thereby theoretically facilitates the neuronal learning process. As shown in figure 2-7 it also helps students to structure the isolated academic contents from lectures to apply their knowledge creatively on new complex problems working under real life conditions.

To evaluate if the findings from the theoretical analysis prove themselves true in reality the following chapters focus on the application of hands-on learning. Chapter 3 and 4 are a collection of experiences with HOL at Stanford University and TUM and an analysis of two specific courses to obtain the effects that hands-on learning elements can have on student learning and the lessons that can be learned from this experiences.
3 Hands-On Learning at Stanford University and TUM

The Hands-On Learning approach is a general instructional method. There are different possibilities how this method can be applied and implemented into the university context. Referring to section 2.3.2 the individual effects are depending on the individual implementation. To show in which ways HOL can be applied this chapter contains a collection of exemplary courses from Stanford University and Technical University of Munich (TUM). Furthermore, there is a summary of various experiences that were made using the hands-on approach.

3.1 Methods

To investigate different ways of hands-on application I worked two month at the ‘Designing Education Lab’ with Prof. Sheppard and her research group at Stanford University. During this time I had the chance to learn from their research findings about the effect of different instructional methods and to conduct a number of qualitative interviews with professors from the engineering department (mainly mechanical engineering) and the design school.

The interviews generally focused on the questions, which different instructional methods the interviewees were using in their courses, which resources they needed and which effects and problems they had experienced. Another relevant issue was the role of hands-on learning in a product design context, where hands-on learning and prototyping in an number of cases was treated equivalent. This is reasonable as long as the contentual learning effect within the product design process (e.g. knowledge that a designed product feature does not work properly) and the methodical learning effect regarding the design process itself (e.g. realizing that early prototyping in the design process helps to obtain informative user feedback) are distinguished. Only the methodical learning effect is relevant for the analysis of HOL as an instructional method.

To investigate implementations at TUM I also conducted qualitative interviews with professors and other university staff, who are involved in hands-on activities. The underlying questions are similar to those at Stanford University. The number of interviewees is smaller as there are less examples at TUM than at Stanford University.

Section 3.2 contains a collection of summaries of different implementations based on the specific interviews with the instructors to show how HOL can be applied. Section 3.3 aggregates experiences made applying the hands-on approach.

In the appendix you can find a list of all interview partners at Stanford University and TUM and the underlying questionnaires.

3.2 Examples

In the following there are summaries of the content and structure of different courses which
show how hands-on learning is implemented into the curriculum at Stanford University. The information is based on interviews with the responsible instructors and the official Stanford University homepage and on my personal experience. The courses are analyzed by the following aspects: Topic, instructor, institution, audience, goal, content, structure, HOL application, resources. The hands-on applications are assigned to the levels of HOL that were introduced in the definition of HOL in section 2.3.1.

3.2.1 ME203 Design and Manufacturing

<table>
<thead>
<tr>
<th>Topic</th>
<th>Product design and manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor</td>
<td>Prof. David Beach</td>
</tr>
<tr>
<td>Institution</td>
<td>Mechanical Engineering Department, Stanford University</td>
</tr>
<tr>
<td>Audience</td>
<td>Undergraduate and graduate students (depth course for ‘Manufacturing’)</td>
</tr>
<tr>
<td>Goal</td>
<td>Each student has to develop his or her own product and manufacture a final prototype.</td>
</tr>
<tr>
<td>Content</td>
<td>Stanford Design Thinking Process (Empathize, Define, Ideate, Prototype, Test), Overview of manufacturing processes</td>
</tr>
</tbody>
</table>
| Structure              | • Weekly lectures, where students are taught the theory of product design and manufacturing.  
                          | • Practical project (during the whole quarter), in which students have to develop their own products and build prototypes  
                          | • Weekly meetings in small groups with a teaching assistant to discuss their design, ask questions and give each other feedback.  
                          | • Final exposition at the end of the quarter where the students present and review their final products. |
| HOL application        | Project: Production of about 50 different prototypes with various complexity (Proof-of-Principle Prototype, Form Study Prototype, User Experience Prototype, Visual Prototype, Functional Prototype)  
                          | HOL Level 3: Design and build |
| Resources              | Access to the Product Realization Lab (PRL)⁹, Material, Teaching Assistants |

³ The PRL is the educational workshop at Stanford University. It consists of a wood shop, a machine shop, a foundry, a metal shop, a plastics shop and a place called ‘Room 36’ where students can work on Laser-Cutters and 3D-Printers. In this workshop students can use the machines and tools and are supervised by teaching assistants who help them when they have problems and teach them how to use the machines.
3.2.2 ME140 Advanced Thermal Systems

<table>
<thead>
<tr>
<th>Topic</th>
<th>Advanced Thermal Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor</td>
<td>Prof. Reginald Mitchell</td>
</tr>
<tr>
<td>Institution</td>
<td>Mechanical Engineering Department, Stanford University</td>
</tr>
<tr>
<td>Audience</td>
<td>All undergraduate students in their last year (capstone course, mandatory)</td>
</tr>
<tr>
<td>Goal</td>
<td>Integration of heat transfer, fluid mechanics, and thermodynamics into a unified approach to treating complex systems.</td>
</tr>
<tr>
<td>Content</td>
<td>Heat transfer, fluid mechanics, thermodynamics, design</td>
</tr>
<tr>
<td>Structure</td>
<td>Pillar 1:</td>
</tr>
<tr>
<td></td>
<td>• Traditional lectures, where students are taught the theory of integrating heat transfer, fluid mechanics and thermodynamics.</td>
</tr>
<tr>
<td></td>
<td>• Traditional tutorials, where students work on example problems under supervision of the instructor.</td>
</tr>
<tr>
<td></td>
<td>• Traditional homework, where students improve their skills by solving independently example problems.</td>
</tr>
<tr>
<td></td>
<td>Pillar 2:</td>
</tr>
<tr>
<td></td>
<td>• Six labs (weekly), where students apply their knowledge by working with real physical objects (e.g. taking measurements) and writing a report each time.</td>
</tr>
<tr>
<td></td>
<td>• One final lab/project, where students have to collaborate in groups to design, build and test a part of a rocket nozzle, write a report and present their results.</td>
</tr>
<tr>
<td>HOL application</td>
<td>1.) Labs: Students handle and work with real instruments → HOL Level 2: Handle and work</td>
</tr>
<tr>
<td></td>
<td>2.) Lab/Project: Designing, building and testing a rocket nozzle → HOL Level 3: Design and build</td>
</tr>
<tr>
<td>Resources</td>
<td>Engines Lab (MERL) + Equipment, Material, Teaching Assistants, Access to the Product Realization Lab (PRL) (only for the final project)</td>
</tr>
</tbody>
</table>

Table 3-2: Summary of ME140 Advanced Thermal Systems

3.2.3 ME218A Smart Product Design Fundamentals

<table>
<thead>
<tr>
<th>Topic</th>
<th>Programmable electromechanical systems design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor</td>
<td>Prof. Ed Carryer</td>
</tr>
<tr>
<td>Institution</td>
<td>Mechanical Engineering Department, Stanford University</td>
</tr>
<tr>
<td>Audience</td>
<td>Graduate students (depth course for ‘Mechatronic’)</td>
</tr>
<tr>
<td>---------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>Goal</td>
<td>Teach students fundamentals about different electromechanical parts and help them to apply their knowledge about programming, electronics and mechanics.</td>
</tr>
<tr>
<td>Content</td>
<td>Transistors as switches, basic digital and analog circuits, operational amplifiers, comparators, software design, state machines, programming in C</td>
</tr>
</tbody>
</table>
| Structure     | • Traditional lectures and video lectures, where students are taught the theory about electromechanical parts, circuits and programming.  
• Traditional Tutorials, where students work on example problems under supervision of the instructor.  
• Continuous labs (weekly), where students apply their knowledge by building circuits or programming devices.  
• One final project, where students have to collaborate in groups to design, build and test/present an electromechanical system/device. |
| HOL application | 1.) Labs: Designing and building circuits using electromechanical parts such as transistors and sensors.  
⇒ HOL Level 3: Design and build  
2.) Project: Designing and building an electromechanical system (e.g. a game)  
⇒ HOL Level 3: Design and build |
| Resources      | Smart Product Design Lab (SPDL) + Equipment, Material, Teaching Assistants, Access to the Product Realization Lab (PRL) |

Table 3-3: Summary of ME218A Smart Product Design Fundamentals

3.2.4 ME310 Product-Based Engineering Design, Innovation, and Development

<table>
<thead>
<tr>
<th>Topic</th>
<th>Engineering design, innovation and development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor</td>
<td>Prof. Larry Leifer</td>
</tr>
<tr>
<td>Institution</td>
<td>Mechanical Engineering Department, Stanford University</td>
</tr>
<tr>
<td>Audience</td>
<td>Graduate students with experience in engineering design (depth course for ‘Design methodology’)</td>
</tr>
<tr>
<td>Goal</td>
<td>Give students experience and tools they need to organize a team and approach a completely new and open design problem</td>
</tr>
<tr>
<td>Content</td>
<td>Stanford Design Thinking Process (Empathize, Define, Ideate, Prototype, Test), Innovation and project management</td>
</tr>
</tbody>
</table>
Structure

- Student teams collaborate with academic partners in Europe, Asia, and Latin America on product innovation challenges presented by global corporations to design requirements and construct functional prototypes for consumer testing and technical evaluation.
- International travel in context of the need finding process
- Presentations in front of all students and the customer

HOL application

Designing, building and testing functional prototypes

⇒ HOL Level 3: Design and build

Resources

Material, Teaching Assistants, ‘The Loft’ (a space where each team has a communal area to work on their project), Access to the Product Realization Lab (PRL)

Table 3-4: Summary of ME310 Product-Based Engineering Design, Innovation, and Development

3.2.5 SMG - Seminar ‘Entwicklung mechatronischer Geräte’

<table>
<thead>
<tr>
<th>Topic</th>
<th>Design and development of mechatronic devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor</td>
<td>Joachim Kreutzer</td>
</tr>
<tr>
<td>Institution</td>
<td>Institute of Micro Technology and Medical Device Technology (MIMED), TUM</td>
</tr>
<tr>
<td>Audience</td>
<td>Students who are at least in their third year</td>
</tr>
<tr>
<td>Goal</td>
<td>Teach students fundamentals about the design and development of mechatronic devices and the ability to acquire further knowledge.</td>
</tr>
<tr>
<td>Content</td>
<td>Fundamentals of electrical engineering, circuit layout, printed circuit boards, soldering, programming of microcontrollers</td>
</tr>
<tr>
<td>Structure</td>
<td></td>
</tr>
</tbody>
</table>
- In theory parts students learn academic contents about electrical components and how to design a mechatronic device.  
- In practical parts students work in pairs and have to design their own circuit board, manufacture it and program the microcontroller. |
| HOL application | Designing, building and testing a mechatronic device  
⇒ HOL Level 3: Design and build |
| Resources | Material, Teaching Assistants, Equipment |

Table: 3-5: Summary of SMG- Seminar 'Entwicklung mechatronischer Geräte'
3.2.6 Result

The introduced variety of possibilities for the implementation of HOL raises the awareness that HOL is not a universal standard concept but an idea that has to be individually fitted to every case of application.

In general, there can be identified two kinds of hands-on application in the introduced courses:

1. **Continuous Labs:** In labs, which are lined up to the lectures, the academic knowledge that is imparted in the lectures, tutorials and homework is applied on a practical problem. Students have to work hands-on to solve problem. The level of HOL can reach from one to three.

2. **Projects:** Projects often include teamwork and a design task, which enables the student’s creativity. In all introduced examples the students have to build a prototype. Thus projects can be classified as HOL level three.

Regardless of the way how HOL is applied, the scope and guise has to be fitted to the specific goal, content and resources.

### 3.3 Experiences and Lessons Learned

Reviewing all conducted interviews reveals a number of experiences that were made frequently by different instructors in different courses and at different universities, which allows the assumption that those experiences are universally valid. In the following those experiences and lessons learned are listed as they can be helpful for instructors who want to implement HOL to prevent complications.

<table>
<thead>
<tr>
<th>Critical Factor</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group size</strong></td>
<td>If every student is supposed to undergo a hands-on experience the group size has to be as small as possible (optimum of 4 students per team). If classes are bigger, it is necessary to split the students into multiple layers of subgroups.</td>
</tr>
<tr>
<td><strong>Space</strong></td>
<td>Especially when students collaborate in teams they need to have access to rooms where they can meet up, discuss and work on their projects.</td>
</tr>
<tr>
<td><strong>Staffing</strong></td>
<td>Hands-on experiences are more individual and personal and sometimes dangerous than traditional approaches. Thus there have to be supervisors who take care of the student’s needs, observe their actions, organize the tasks and coordinate the groups.</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>As hands-on tasks are more complex and need more organization and coordination they consume a lot of time. Both on the staff side (e.g. for grading) and the student side.</td>
</tr>
</tbody>
</table>
### Facility (workshop)

- **Machine tools**
- **Hand tools**
- **Staff**

Depending on the hands-on task it is necessary to have access to a fully equipped workshop. This workshop does not only have to have the needed machine tools and hand tools but also has to provide supervising staff to train students on the machines and render assistance.

### Material

- **Consumables**
- **Equipment**

Even if a class does not require a workshop there has to be equipment for the hands-on task and consumable material that the students can use.

However, a number of instructors does intentionally not provide all the required material and tools to the students who then have to manage how to get access to the needed items. They believe that this procedure is closer to working reality and increases the commitment of the students.

### Theory Trade-Off

Designing a course means composing different instructional methods to a set of course elements that are meant to lead to the achievement of the individual course goals. Figure 4-1 and 4-4 show two examples. The sum of all elements has to be adjusted to a course specific time frame. As a consequence there is a general trade-off between the time-efficient impartation and immersion of academic knowledge and the time consuming practical application in projects and hands-on activities. Professor Mitchell from Stanford University describes this problem as follows:

"YOU HAVE TO TELL THEM [THE STUDENTS] THREE TIMES: FIRSTLY YOU HAVE TO TELL THEM WHAT YOU ARE GOING TO TELL THEM. SECONDLY YOU HAVE TO TELL THEM. AND THIRDLY YOU HAVE TO TELL THEM WHAT YOU JUST TOLD THEM. IMPLEMENTING LABS AND HANDS-ON PROJECTS ONLY LEAVES TIME FOR TELLING THEM ONCE.“ (MITCHELL, 2014)

### Team dynamics Trade-Off

Working on projects in teams is fun and motivates the students. However, teamwork comes along with team dynamics and team/project management. Taking care of those tasks requires time that the students cannot spend on their project or the lecture and can belie the expectations.

### Research Trade-Off

If facilities and equipment is used for a number of courses and research projects at the same time there can be complications regarding the capacity. Thus it is recommended to separate research and education workshops.

---

**Table 3-6: Critical factors for the successful implementation of HOL**

Regarding the effects of implementing a hands-on element into a course there were the
following shared results:

1. HOL gives students a feeling for the things they are dealing with in the lectures (e.g. quantities and concepts) and thus increases their understanding.
2. Working hands-on is fun and increases students’ motivation.
3. HOL and especially working on their own ideas lets students realize that they can apply their knowledge and enables their creativity and initiative.
4. Interaction in class increases attention and engagement.

At last, there has been one statement that is not relevant for the instructional evaluation of HOL in general as it focuses on design engineers but that was made in almost every interview. Both at Stanford University and TUM the professors and teaching staff hold the belief that people can only design properly if they know about manufacturing and that people can only know about manufacturing if they manufacture. Thus if students are supposed to be educated to become designers they have to go through this iterative process of designing, manufacturing/prototyping and testing. Consequently, according to the interviewees, Prototyping and thereby HOL is an essential part of educating engineers who want to work in a design context.

Concluding, the experiences from Stanford University and TUM clarify that there is a number of critical factors that decide about success and failure of HOL applications. In comparison to other instructional methods such as lectures or tutorials hands-on applications require a lot of resources and thus funding. Only if the necessary conditions are fulfilled HOL is an appropriate approach. Consequently, the decision for or against HOL has to be made carefully and individually for each course.
4 Analysis of ENGR 14 and GEP+TUTOR

In the following sections two different courses are analyzed in detail regarding their structure and use of hands-on learning and their evaluation by participating students. The first course is ‘ENGR14: Introduction to Solid Mechanics’, an engineering fundamentals course from Stanford University (CA, USA) taught by Professor Sheri Sheppard. I spent about one month on observing the class sessions and interviewed involved teaching staff. Furthermore, I had access to the course documents, evaluations and research that has been made on this course. The second course is ‘GEP: Grundlagen der Entwicklung und Produktion’, a fundamental class for mechanical engineering students at the Technical University of Munich (TUM) (BY, Germany) taught by Professor Udo Lindemann. This course is tied to a curricular soft-skill program called TUTOR. To analyze this course I both talked to the responsible teaching staff and made a survey within the students to check if the instructions showed the desired effects.

4.1 Content and Structure

<table>
<thead>
<tr>
<th>ENGR 14</th>
<th>GEP + TUTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Professor</strong></td>
<td><strong>Professor U. Lindemann</strong>&lt;br&gt;(Prof. Zäh, Prof. Volk)</td>
</tr>
<tr>
<td><strong>Institution</strong></td>
<td><strong>“Lehrstuhl für Produktentwicklung” and “Zentrum für Sozialkompetenz und Managementtrainings”, Department for Mechanical Engineering at TUM</strong></td>
</tr>
<tr>
<td><strong>Duration</strong></td>
<td><strong>14 weeks (one semester)</strong></td>
</tr>
<tr>
<td><strong># Students</strong></td>
<td>~ 800</td>
</tr>
<tr>
<td><strong># Advisors</strong></td>
<td>GEP-Team: 6 Assistants (technical)</td>
</tr>
<tr>
<td><strong>Educational system</strong></td>
<td>GEP-Project: 60 TUTORs (social)</td>
</tr>
<tr>
<td>When American students graduate from high school, they can either go to a Community College for two to three years or they can directly apply for a university. At the university the academic year is divided into four quarters: Fall, winter, spring, summer. Most students take courses from fall until spring and use the</td>
<td>When German students graduate from high school and decide to study at a university, they do not only have to apply for a university in general as in the USA but they have to apply for a specific bachelor degree program such as mechanical engineering, philosophy, history, medicine, etc.. Depending on the program they may</td>
</tr>
</tbody>
</table>
summer quarter for internships, work, travels or free time. In their first year they start as undergraduate students without a specific subject. They can choose their courses from a selection of fundamentals courses from all fields (Humanities, engineering, Science, etc.). After two years they must have chosen a major and a minor. After four to five years students graduate and can apply for a master program, which takes another two years. In their master they have to choose a depth but are flexible in choosing their other courses. To get their degree they also have to write a thesis. At least half of the engineering courses both in the undergraduate and the master programs are project-based or at least include some practical experiences.

### Placement in the degree course

<table>
<thead>
<tr>
<th>ENGR 14 is a fundamentals course in engineering, which every first year undergraduate student can take. Most of the students do not have any previous knowledge about the subject or any experience in this field but have various different backgrounds and interests. For most of them ENGR14 is the first course where they get in touch with engineering.</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEP is an obligatory course for all mechanical engineering students in their second semester. The students have similar previous knowledge in math, physics, mechanics, chemistry, electronics and computer science from their first semester and some practical experience from the required previous internship (at least eight weeks).</td>
</tr>
</tbody>
</table>

### Goals

**Students who complete this course have the ability to …**

a) explain and demonstrate the role that analysis and modeling play in engineering design and engineering.

**Students who complete this course have the ability to …**

a) apply different methods of product development (and manufacturing).

b) work in teams and be aware of
b) apply analytical skills for evaluating structural response.

c) explain the foundations for concepts and equations on structural integrity, including the limitations of these concepts and equations.

d) communicate about systems using mathematical, verbal and visual means.

e) describe how engineering analysis fits into the larger framework of professional engineering.

difficulties that can arise with that.

c) describe the relevance of all fundamental subjects/courses within the larger framework of professional engineering.

<table>
<thead>
<tr>
<th>Table 4-1: Facts and Figures of ENGR14 and GEP+TUTOR</th>
</tr>
</thead>
</table>

### 4.1.1 ENGR14

In ENGR14 students learn about the fundamentals of mechanics in solids. The main topics are: Forces and Moments, Equilibrium, Free-body Diagrams, Trusses, Beams. During the quarter Prof. Sheppard makes use of several different instructional methods to equip her students with the specific knowledge and accomplish the goals:

1. **Lectures**: Theory lectures are the part of the in-class sessions where the academic content is introduced. Almost every session starts with a traditional lecture part, which takes in average about half of the class time. In those parts Prof. Sheppard or one of her assistants presents theoretic fundamentals of solid mechanics which provides the basis for all other class elements. Additionally hand-outs are provided for almost every lecture and reading material is recommended.

![Figure 4-1: Course structure of ENGR14 (image by author)](image)
2. **In-Class Exercises**: To solidify the theoretic concepts that are introduced in the lecture parts, either within different lecture parts or subsequent to a lecture, students work in class in teams or alone on problem sets. While working on those exercises the professor and the assistants answer questions and help students when they have problems. To ensure an organized supervision the class is divided into four subgroups, of which everyone has its own responsible assistant. All assistants are present during the whole class time.

3. **Homework**: During the quarter the students have to complete six homework assignments matching the six course topics. Those assignments contain theoretical problem sets and have to be processed during one week each independently by every student. All six homework assignments represent 20% of the final grade.

4. **Exams**: There are three exams. One in-class exam after three weeks which counts 10% of the grade. One take-home exam in week eight which counts 20% and the final in-class exam at the end of the quarter which counts another 20%. All in all the exams represent 50% of the final grade. Every exam has to be solved independently and without help from anyone.\(^\text{10}\)

5. **Labs**: There are five labs during one course: Tower Design, Longboard Design 1, Hyatt Case Study, Bicycle Analysis, and Longboard Design 2. The students have to work in class in small groups on hands-on exercises under supervision of the teaching staff. For example in the Longboard Design 1 Lab students calculate the stresses and moments in a beam and measure deflections of beams with different material to get a feeling for how the stiffness or Young’s Modulus is related to the deflection and to see limits of theoretic concepts.

\[\text{Figure 4-2: Students in ENGR14 measuring the deflection of a beam the Longboard Design Lab 1} \]

(image by author)

\(^{10}\) In Stanford University there is an agreement called ‘Honor Code’, which every student has to acknowledge. By that a student promises among others to work independently on take-home exams, not to give or receive any help. A violation can cause a suspension and community service.
In the bicycle analysis lab students have to bring their own bikes to the classroom to measure the efficiency of gears and get a feeling for the relation of rotational speed and torsional moment. After every lab each group has to hand in a lab sheet with the results. The lab results and in-class exercises count 10% of the final grade.

6. Projects: In addition to the labs there are two projects which last longer, are more complex and are more independent than the labs: The Bridge Project and the Independent Study.

In the Bridge Project students have to design, build and test their own small truss bridge. The Bridge Project lasts two weeks. Before the project starts the students have to get together in groups of four. In lectures and in-class exercises students learn fundamentals about trusses and how to calculate frameworks. At the project kick-off the teams get their task and the material. The task is to design and build a truss bridge that fulfills given constraints (geometry, critical loads) out of balsa wood. Within the first week each group has to come up with two distinct bridge designs and their analysis’ (this is homework 5). In the second week the groups have to build one of those designs out of balsa wood and wood glue and write a report on the whole project (design, analysis, construction, testing). In one class session the groups test their final bridges and get a first review on their reports. Furthermore, there is an integrated competition for the least weight and for an unusual design. At last the students have to hand in a peer-review sheet to evaluate their team members and the final report. The whole project is designed to provide a cheap hands-on teamwork experience. Although the contentual task is restricted by several assumptions the way of working is similar to the real world.

In the Independent Study (Project 2) students work in pairs on a self-chosen topic and apply their knowledge about solid mechanics on a specific topic related question. In a final poster session they present their results and show how they applied the different techniques and concepts from the lecture. These two projects result in another 20% of the final grade.
7. **Miscellanea:** To help the students manage all those tasks, there are office-hours (in total 17 hours per week: 2 h Prof. Sheppard, 15 h Assistants) where students can ask questions or get additional information. Furthermore, students have to deal with non-technical tasks such as writing technical reports, render elevator pitches, creating posters or conducting Business Case Studies. By that, students are supposed to get introduced to and comfortable with common tasks in the daily routine of an engineer. At last, students participate in an extensive evaluation. On the one hand this evaluation is used to improve the lecture as students reveal which course elements contributed to which course goals. On the other hand it solidifies the understanding of solid mechanics as students have to reflect their knowledge and create a concept map which relates all course relevant techniques and concepts.

To sum up, in ENGR14 there is a high number of course elements and variety of instructional methods. Additional to traditional lectures, exercises, homework and exams there are weekly hands-on elements in the form of in-class labs or projects. The ratio between teaching staff and students (~ 1:12) allows an intensive support of every single student.

### 4.1.2 GEP+TUTOR

In GEP+TUTOR students learn about the fundamentals of product development and manufacturing engineering. The main topics are: Requirement engineering, problem structuring, creativity techniques, decision making, systems and models, material science, design and fundamentals of manufacturing engineering. During the semester the instructors make use of different methods to equip their students with the specific knowledge and accomplish the goals:

1. **Lectures:** There are one or two lectures per week that last 90 minutes each. In the lectures the academic content is introduced. The whole lecture part is subdivided into the product development part and the production engineering part. The first part deals with topics on product development such as requirement engineering, structuring, creativity methods (e.g. morphological analysis, 6-3-5 method), decision-making (e.g. weighting schedule), systems engineering, material science and design. Central element is a product development method called ‘Münchner Vorgehensmodell’ by Prof. Lindemann. The lectures are provided by the Institute for Product Development (Prof. Lindemann, MW, TUM). The second part deals with topics on production engineering such as manufacturing techniques (e.g. forming, mating) or choice of appropriate materials. Those lectures are provided by the Institute for Machine Tools and Industrial Management (Prof. Zähr, MW, TUM) and Institute for Forming and Casting (Prof. Volk, MW, TUM). After each lecture there is a one-hour **consultation-hour** offered by the teaching assistants where students can ask technical topic related questions.

2. **GEP-Project:** In the GEP-Project students apply the development methods from the lectures to design their own product and improve their soft-skills by collaborating in teams of 10 to 15 people.
The GEP-Project is part of TUTOR which is a curricular soft-skill program that lasts two semesters. It is a cooperation between the Institute for Product Development and the Center for Soft-Skills and Managementtrainings (‘Zentrum für Sozialkompetenz- und Managementtrainings ZSK’, MW, TUM). In the first semester the students build teams of 10 to 15 people and attend interactive workshops about presentation, communication, teamwork and creativity. Each group has its own TUTOR who supervises the team regarding team dynamics and social aspects for the whole year. The TUTORs are older students who get a specific training before they are assigned to the groups. In the second semester which is the practical semester the students have to use their skills to work on a real product development problem in the context of GEP. This method of integrating soft-skill training into engineering education is called complementary teaching.

The GEP-Project lasts nine weeks. In the first week of the course the students get a design task which defines the target group and the initial situation/problem. In the following weeks the groups have to work on this task and apply different methods that are theoretically and exemplarily introduced in the lectures to develop their own product concept and design a CAD model of their product. After nine weeks a TUTOR jury rates all products regarding their degree of innovation and other parameters (at this point the correct application of design methods is irrelevant).

![Figure 4-2: Course structure of GEP+TUTOR (image by author)](image)

3. **TUTOR Competition:** After the GEP-Project ten teams have the possibility to realize their design concept and build a physical prototype. The decision which teams participate in the competition is based on the product assessment by the TUTOR jury and the motivation of the students. The competition lasts three weeks. Every team gets a material budget of 200€ and contact to a research workshop of the ME department where they can use selected machine tools and build their prototype (The selection of tools is determined by the particular master mechanic). If the students are not allowed to work on a machine themselves the craftsmen take over the manufacture. After three weeks of building a jury of professors and other experts elects the best product and rewards the team with an adventure coupon.
4. **Exams:** There is an oral exam in week 11 where every group (not only those who participate in the competition) has to present a poster where its product concept and the applied methods are explained. The assessment is based on integrity and the correct application of design methods. The degree of innovation or the product itself is not relevant. The presentation is not graded but passing the oral exam is a requirement for being admitted to the final written in-class exam which is at the end of the term. The final exam covers all content from both lecture series. Its result defines the final grade at 100%.

To sum up, in GEP a traditional lecture without specific exercise lessons is connected to a problem-based, creative product development project, where students apply their methodological knowledge from the lecture and develop their own product concept. Additionally a fraction of about 15% of the students has the possibility to build a physical prototype and have a hands-on experience. The connected soft-skill program supports teamwork and creativity. The ratio between technical teaching staff and students (~ 1:115) and the brief TUTOR training do not allow an individual grading of all course elements but only of one final exam.

### 4.1.3 Hands-On Elements in ENGR14 and GEP+TUTOR

Comparing the instructional elements of ENGR14 and GEP+TUTOR shows different possibilities of applying the general hands-on learning approach on engineering education. In the following table the course elements are assigned to the used Level of HOL. The assignment bases on the previous section and the definition of HOL and level concept that was introduced in section 2.3.1 of this work. Zero means that there is no use of HOL. One, two and three stand for the different levels of intensity.

<table>
<thead>
<tr>
<th>Course Element</th>
<th>Level of HOL</th>
<th>Course Element</th>
<th>Level of HOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lectures</td>
<td>0</td>
<td>Lectures</td>
<td>0</td>
</tr>
<tr>
<td>Exercises</td>
<td>0</td>
<td>Exams</td>
<td>0</td>
</tr>
<tr>
<td>Homework</td>
<td>0</td>
<td>GEP-Project</td>
<td>0 (but PBL)</td>
</tr>
<tr>
<td>Exams</td>
<td>0</td>
<td>TUTOR Competition</td>
<td>3</td>
</tr>
<tr>
<td>Labs</td>
<td>1-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projects</td>
<td>P1: 3, P2: 0 (but PBL)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 4-2: Level of Hands-on learning in ENGR14 and GEP+TUTOR*

The following sections show which effects the different hands-on elements had on the participating students.
4. Analysis of ENGR 14 and GEP+TUTOR

4.2 Evaluation by Participating Students

In the last section ENGR14 and GEP+TUTOR were analyzed regarding their content and structure and the course elements in which the hands-on approach has been applied were identified. This section summarizes different course reviews that were taken on ENGR14 and GEP+TUTOR to obtain the effect that the hands-on elements had on the student learning process and overall experience.

4.2.1 Methods

This section is based on the following sources:

1. Internal course review on ENGR14 (2013-2014 Autumn) by participating students. This review contained three tasks:
   a. Modifying the official course description to be more accurate based on the course experience.
   b. Indicating the degree of achievement for every course objective and providing specific examples of contribution (e.g. homework, labs, projects).
   c. Creating a concept map of one’s individual understanding of the course, in which the topics and concepts (e.g. beams, forces, FBDs) are structures by linking them through connector words (e.g. cause, include, result in).

Regarding the underlying question about the effect of different course elements, the following summary focuses on the results of task b.

Number of participants: 84

2. Study by L. Eaton, a former participant of ENGR14, on task b of the internal course review of ENGR14 (2012-2013 Autumn). In her study she structures and interprets the data regarding the effect that different course elements had on the achievement of the course goals.

Number of participants: 79

3. Official Teaching Evaluation Summary (2013-2014 Autumn) of ENGR14 which includes ratings on the instructor, the course structure and integrity, the content and organization and comments on the instructor, textbooks and reading material, assignments and exams.

Number of participants: 60

4. Survey among GEP+TUTOR participants who participated in the competition in summer 2013 and thus had an hands-on experience by manufacturing their own prototype. This survey investigates the effect of different course elements on the learning process and overall experience (including fun and motivation). The complete list of questions can be looked up in the appendix (A3 Survey on GEP+TUTOR).

Number of participants: 21

In the following the sources are referenced by calling them Source 1, Source 2, Source 3 and Source 4 referring to the numbering above.
4.2.2 Results in ENGR14

Focusing on Hands-On Learning the student evaluations of ENGR14 from Source 2 revealed the following effects of different course elements on the learning experience of participating students:

- Course goal a (analysis and modeling) had the highest achievement rating of 3.35 (mean value on a 0-4-scale), followed by goal b (structural integrity analysis), c (structural integrity concepts), and d (system communication) which averaged all around 3.0. Goal e (structural intuition and questioning) had the lowest achievement rating of 2.8.

- The achievement rate correlates with the number of examples that were mentioned in task b for contributing to the individual course goals. The participating students listed in total 101 examples for goal a, 95 for goal b, 84 for goal c, 91 for goal d, and 79 for goal e.

- The overall most mentioned example was the Bridge Project (P1) with 96 counts out of 450 in total (followed by truss analysis with 52 counts). For each goal it showed up in the top four contributing elements and was ranked first in ‘Analysis and Modeling’ (goal a) and ‘Structural Integrity Analysis’ (goal b). 37 times (out of 101 counts in total) the project was mentioned to contribute to the achievement of goal a, 27 times (out of 95 in total) for the achievement of goal b. This means that almost 50% of all participating students mentioned it in context of goal a, almost 35% in context of goal b.

- The rating of labs was diverse: Whereas the longboard lab showed a remarkable contribution to goal a (18 counts out of 101 in total, rank 2) the labs in general were mentioned in average about 4.5 times.

![Figure 4-3: Number of times a course element was mentioned in the course review of Source 2 to be contributing to a specific course goal. (EATON, 2013)](image-url)

The summarized results from Source 2 are verified by Source 1 which shows a similar student feedback regarding the bridge project and an increased contribution of the labs in
4. Analysis of ENGR 14 and GEP+TUTOR

general (i.e. the number of lab counts regarding goal a increased from 5 in Source 2 to 15 in Source 1).

Source 3 lists comments of participating students on various aspects of the course. In the following the comments regarding the hands-on assignments are extracted and grouped:

| Positive feedback | ‘Assignments are very useful at solidifying understanding of the material and help to clarify and consolidate key concepts.’ |
|                   | ‘Bridge project was super fun and I felt like I learned a ton. I would enjoy another group project like that.’ |
|                   | ‘I enjoyed the projects immensely; they were a lot of fun!’ |
|                   | ‘I can't wait to apply what I've learned to solve real world problems.’ |
| Negative feedback | ‘Lab is tedious and dull.’ |
|                   | ‘Too much for one quarter. It stresses more than it helps.’ |
|                   | ‘I felt like sometimes in lab, I was just plugging numbers into given equations and wished I had understood the equations' derivations better.’ |
| Suggestions       | ‘Still, homework is necessary to solidify knowledge but not too long and time consuming.’ |
|                   | ‘More building!’ |

Table 4-3: Comments on ENGR14 by participating students (extracted from Source 3).

4.2.3 Results in GEP+TUTOR

The survey among those GEP students who participated in the TUTOR-Competition and worked practically manufacturing their prototype led to the following results:

- 95% of the students only used hand tools.
- About 60% stated that the TUTOR-competition and thus the manufacturing of the prototype was the most fun part of the course followed by the GEP-project and eventually the lectures.
- The two strongest factors regarding the student’s motivation were teamwork (2.5, mean value on a 1-8-scale) and working on their OWN idea (2.7). Number three was practical realization (3.3) having a relatively high standard deviation (2.2) and variance (4.6).
- More than 50% of the students said that the GEP-Project had a slight to moderate influence on their result in the exam, their motivation for the course and their engineering practice skills. About 40% said it helped them to understand the relevance of other engineering classes and almost 25% said the project influenced the result of other engineering exams and their motivation for the study program.
In comparison, almost 25% said that the physical realization had a slight to moderate influence on the GEP exam result and 10% said it had an influence on other exams. Almost 40% said that it increased the motivation for the course and the study program moderately. About 50% confirmed a moderate influence on the understanding of the relevance of other classes. And finally more than 75% said that the physical realization had an influence on their engineering practice skills of which 20% affirmed a strong to crucial influence.

- 60% of the students would like to work in projects more often and 75% want to have Hands-On experiences frequently.

In the comments participating students could give feedback on the course and suggest improvements. In the following the basic aspects are summarized:

<table>
<thead>
<tr>
<th>Positive feedback</th>
<th>Teamwork and experiencing team dynamics.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Working <strong>practically</strong> and in projects.</td>
</tr>
</tbody>
</table>
4. Analysis of ENGR 14 and GEP+TUTOR

Negative feedback

Inappropriate workload regarding the rewards (amount of credit points, grading).

Unfair distribution of the workload among student groups.

Limited access to machine tools and hand tools.

Competition timeframe in conflict with exams.

Vague definition of the task.

Groups too big for HOL (only about four students really manufactured the prototype).

Suggestions

More time for the manufacturing task within the competition.

Access to a workshop.

Precise communication and transparency regarding the timeframe and grading process.

Table 4-4: Comments on GEP+TUTOR by participating students (extracted from Source 4).

4.3 Analysis of Hands-On Learning in ENGR14 and GEP+TUTOR

Based on the studies and reviews introduced in the last section the following table lists learnings about the general influence of hands-on learning on the learning process of engineering students.

<table>
<thead>
<tr>
<th>Learning</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Do-Effect</strong></td>
<td>The review of the bridge project shows that the instructional method of hands-on learning can have a strong positive influence on the learning process of students. However, the differences among the lab assessments and the results from the GEP-survey lead to the assumption that this influence is not generally valid for every course and every hands-on experience.</td>
</tr>
<tr>
<td><strong>Motivation and Emotion</strong></td>
<td>No matter in what context the hands-on approach on learning was used, it showed a positive effect on the student’s motivation and increased the fun level of the individual course for the majority of the students. Recalling section 3.2 positive emotions, such as fun, and motivation neuroscientifically and</td>
</tr>
</tbody>
</table>
4. Analysis of ENGR 14 and GEP+TUTOR

Psychologically influence the learning process beneficially and increase the willingness to learn. The result of the GEP+TUTOR study, that teamwork and giving students the opportunity to work on their own ideas increase motivation and thus support the learning process, affirm further assumptions from section 3.2

### Engineering Practice Skills

Recalling the need for highly skilled engineers, not only academically but also practically, HOL is an appropriate method to create competence in engineering practice. Although a direct effect of HOL on the acquisition of academic knowledge was not measurable, the GEP+TUTOR study revealed an indication for the effect of HOL on the engineering practice skill level of students. The TUTOR competition (practical/physical realization) had a bigger perceived influence on the practice skill level than the GEP project. As the activity of building and the interaction with physical objects is the only contentual difference between those two course parts, the increase in engineering practice skill change can be traced back to the use of HOL.

### Engineering Thinking and Comprehension

Hands-on experiences can improve engineering thinking and raise a consciousness towards the meaning and relevance of engineering classes. Both studies on GEP+TUTOR and ENGR14 show that hands-on experiences can improve engineering thinking (regarding system communication and problem solving) and raise a consciousness towards the meaning and relevance of engineering classes. This could be caused by the circumstance that if students interact with a real physical object they have to drop all assumptions, analyze the problem in its whole complexity and handle unexpected problems as in reality everything is fraught with uncertainty. For solving those problems they might need knowledge from different subjects and thus understand the importance of different courses.

### Resource Management and Rewarding

Hands-on experiences are more time consuming and expensive than traditional imparting methods. Thus the use of this As the course review of ENGR14 shows, the trade-off between the impartation of academic theories and practical application is also
4. Analysis of ENGR 14 and GEP+TUTOR

The approach has to be carefully adjusted to the focus of the course and the effort has to be rewarded appropriately. Experienced by students. Students said that the amount of hands-on elements in ENGR14 crossed the critical point where the well-intentioned motivating hands-on experiences become an academic burden.

In GEP+TUTOR another problem appeared: Those students who participated in the competition and thus spent more time on the course than their fellow students felt unjustly treated and complained that the chargeable credits for the course are inappropriate related to the effort and that some elements had no influence on the final grade.

The time needed for preparation, supervision and assessment of hands-on elements is higher than in traditional lectures. And as teaching staff has to get paid, financial aspects have to be involved into course design as well.

Access to Tools and Material

Depending on the hands-on task students need access to a workshop to work on machine and hand tools. GEP+TUTOR shows that for some tasks the access to a workshop with machine and hand tools is necessary. As students are manufacturing amateurs there also have to be introductory and safety courses on the machines. Furthermore, students need material to build their prototypes. This also leads to a financial burden. However, the bridge project shows that there are ways to realize hands-on projects with costs of less than 3$ per student.

Class Size

HOL is only possible in small groups. If classes get bigger, they have to be divided into different layers of subgroups, which increases the organizational effort. Scaling a hands-on activity does not only proportionately increase the resources but also increases the organizational complexity which makes it even harder to realize one and the same activity in a course such as GEP+TUTOR with more than 800 students than in one such as ENGR14 with less than 100 students. Furthermore, the bigger the class the harder it is to manage all different skill levels to neither underchallenge nor overchallenge students, or in other words to create flow.

Table 4-5: Learnings from ENGR14 and GEP+TUTOR regarding implementation and effects of HOL.
All in all, the decision if it is appropriate to implement a hands-on experience into a university course depends on the course goals, available resources and the number of students and has to be individually made for each course.

At last it is supposed to be clear that hands-on elements cannot replace traditional lectures, homework and other methods of theoretic knowledge transfer. They provide the basis for the profound education of a highly skilled engineer. In a general university course the hands-on approach on learning can only help making this knowledge applicable, increasing the student’s motivation and setting free creativity.

4.4 Recommendations for HOL in ENGR14 and GEP+TUTOR

In this last section I derive recommendations regarding the use of hands-on learning in ENGR14 and GEP+TUTOR. Those recommendations are based on the neuroscientific and psychological findings in chapter 2, the interviews with experts in the context of engineering education in chapter 3, and the analysis of course structures and reviews in chapter 4.

4.4.1 ENGR14

The Bridge Project

The bridge project was among all analyzed instructional elements the element with the best feedback regarding both solidification of knowledge and fun. This is presumably because all requirements from section 2.2 are fulfilled. As the goal of the course is not to increase the student’s skills in working on industrial machines, it is sufficient to let them work with balsa wood and glue. This course element should not be deleted from the syllabus.

The Labs

There are different labs with various complexity and difficulty. This variety can lead to the risk of confusion, disorientation and overchallenging the students. On the other hand some individual labs were perceived as dull and underchallenging. Especially at Stanford University, where there are over-average intelligent students, the labs and all other course elements should be contentually demanding and engaging and have a deep theoretical foundation. Nevertheless, the temporal and structural setup must be clear and transparent. As there were a number of labs that, according to the reviews, did not have a strong influence on the achievement of the course goals, this could be a place to start reducing the scope and variety of the course. One way could be to narrow on those course elements that each had the most contribution to one goal so that there are less elements with a higher intensity and difficulty. The gained time could also be spent on focusing on some academic aspects such as equation derivation. However, in the process of deleting course elements from the syllabus the teaching staff has to mirror carefully the effect on the student learning process as elements, which do not have a high influence on learning from the student’s point of view, may have a significant effect in the end but shape the knowledge subconsciously.
Overall Structure

From my personal perception, which was affirmed in some interviews, students at Stanford University generally have strong interests and a high engagement. Additionally, the university and its surroundings provide a number of distractions (free-time activities, companies, start-ups, etc.). This attracts the attention of students who may struggle paying attention to their courses. Thus, it is important to help students stay focused. One way to keep students satisfied, motivated, and engaged is gamification. Gamification means applying game design techniques and game elements on a non-game context and is especially effective for people born after 1971 (WERBACH, 2014). Instantaneous and frequent feedback, rewarding, and competition are only three examples how student can be motivated and their attention can be increased by use of gamification. Some of those elements can already be recognized in ENGR14 (e.g., transparent grading, special design challenges within the bridge project, cooperation in teams). Implementing elements like leader boards may be helpful and motivating for some students.

However, this course is not a solid mechanics course for mechanical engineers but an introductory course for every student who is generally interested in engineering. Thus, the amount of course elements, the difficulty, and competition should not pass the point where students lose fun and perceive the course as an academic burden.

Summary

ENGR14 is a well-structured course with a high variety of instructional methods and many hands-on elements, which motivate the students and give them an impression of engineering thinking and practice. The bridge project is a parade example for a cheap and effective way to use HOL to solidify academic theories and concepts. It solely has to be paid attention to the overall effort and the attention of the students as a high variety of course elements can cause distraction and overextension.

4.4.2 GEP+TUTOR

GEP Project

The definition of the task was very open. That caused confusion and demotivation as the students did not know what to do in the beginning of the project. To enable students to start generating product ideas and working on their project from the first day on, the tasks should be defined more precisely, students should be given an example for what they are supposed to do, and specific connections should be drawn between the introduced product development methods in the lecture and the stages of the project.

TUTOR Competition

The most mentioned topic that was complained about in the survey was the rewarding and an unequally distributed workload as those students who participate in the competition have to spend more time on the course than the others and do not get a bonus for that. Furthermore, only a fraction of the original group really manufactures the prototype. Students want to be rewarded for their efforts (CHATFIELD, 2010). If they feel unfairly treated, they lose their curiosity, motivation, and studying pleasure. However, chapter 2
showed that forcing people to do something that they do not want to do causes negative emotions and destroys motivation. A number of recommendations arise out of this problem:

- The competition should be a **voluntary** option for those students, who are interested in product design and especially manufacturing.
- There have to be a **small group** of about four to six students in which every member is involved in the manufacturing process.
- The effort that students invest into the competition should be either rewarded with additional credit points or with a bonus for the final grade.

Furthermore, there are some recommendations regarding the framework conditions of the competition:

- The prototyping process should start with the beginning of the project. In the lecture product development is introduced as an iterative process of designing, prototyping and testing. Isolating the manufacture of a prototype at the end of the project is contradictory to the original process of product design.
- Students should have access to a workshop, where they can learn how to use and afterwards work on machine tools and hand tools, to build complex products and set free their creativity.

**Overall Structure**

Regarding the overall structure of the course and the linking between different course components there is a number of opportunities:

- Every element of the course should be part of a **transparent reward system**. Involving components such as the project, poster-presentation and final product into the grading process makes those components meaningful, keeps students engaged and motivated.
- The lecture part on production engineering should be linked to the competition. The product development part provides the academic foundation for the GEP project. In the same way the production part provides an academic foundation on manufacturing which is currently not applied.

Both an intense supervision, transparent and comprehensive rewarding, and hands-on experiences for the students require a lot of resources. There are a number of ways, how those problems can be solved:

- The grading process can be improved by applying the concept of peer grading where students assess each other by writing evaluations and correcting tasks. That would not only save resources on the staff side but also improve the students’ soft skills.
- Recording the lectures, which provide the academic foundation, and providing the knowledge in a video-based way for example by creating a MOOC (Massive Open Online Course) would allow an individual learning speed as students could listen to the lectures at home and repeat sections which they do not understand. The in-class time could be used to interact with the students, have guest talks or answer questions. This teaching concept is called inverted classroom.
- Whatever the case may be, a close cooperation between the TUTOR staff and the GEP staff is necessary.
One positive thing that, according to the survey, increased the motivation was the competitive context and teamwork. Those two aspects are examples for gamification. Gamification means applying game design techniques and game elements on a non-game context and is especially effective for people born after 1971 (WERBACH, 2014). Instantaneous and frequent feedback, rewarding and competition are only three examples how student can be motivated and their attention can be increased. Using the concept of gamification could be another approach to increase the curiosity, excitement and engagement for the course (CHATFIELD, 2010; WERBACH, 2014).

**Summary**

Summing up, in GEP+TUTOR there are already a number of positive elements such as teamwork, competition, practical application and the involvement of students’ ideas and interests. Those elements provide extrinsic motivation and are, referring to section 2.3, important requirements for a beneficial learning environment. As the course structure has been implemented for the first time in 2013 there are some organizational aspects such as rewarding, as fair perceived workload distribution and equal and improved conditions for hands-on experiences that can be improved to increase the learning experience of students.
5 Discussion

In the following I discuss the methods that were used in this work and the sources that this thesis is based on.

Neuroscientific and psychological analysis

Regarding the neuroscientific analysis in chapter 2 it has to be minded that the field of neuroscience is relatively young compared to other fields such as psychology and that the majority of the brain’s functionality still has to be scrutinized. However, those findings that were introduced in the first part of this thesis are scientifically confirmed by different researchers and have been proven valid in several empirical studies such as ‘Improved learning in a large-enrollment physics class’ (Wieman, Schelew, & Deslauriers, 2011). This means that the requirements which were deduced in section 2.3 are universally valid.

Interviews

Regarding the interviews a number of aspects has to be mentioned that restrict the universality of the summarized findings:

- The interviewees were all employed at Stanford University or Technical University of Munich. The majority worked at the mechanical engineering department at Stanford University and was part of the design group.
- The interviews all based on the same questionnaire but as they were qualitative interviews, which did not only serve the purpose of this thesis but were also used for another academic work, they diverged regarding their focus and outcome. However, the basic questions were the same.
- There can always be a difference between what people perceive and think and the reality. This leads to an uncertainty which is attached to every statement.

This does not mean that the findings are not true or that the derivations are not valid but that they have to be verified by analyzing other courses in other universities with different circumstances and interviewing people from different backgrounds with a questionnaire which is designed to provide comparable data and that is strictly followed.

Analysis of ENGR14

The results and findings from ENGR14 are based on three course reviews and have been affirmed in a number of interviews with the teaching staff and other experts in the field of engineering education. Thus the analysis of the course and the applied hands-on experience is reasonable.

There is only one uncertainty which appears in the Official Teaching Evaluation Summary, in which a number of students uses the term ‘assignments’ in their comments. It is not clear
if they are referring to homework assignments, lab assignments or the projects. Thus in those cases the statement cannot unambiguously be referred to hands-on elements such as projects and labs.

**Analysis of GEP+TUTOR**

The statements that are made based on the study on GEP+TUTOR have to be observed carefully as the underlying survey has a number of weak spots that make those statements debatable:

- The number of interrogated students (21) and the fact that all students come from one year challenge the universality.
- Within the survey some students contradict themselves and do not represent consistently one position.
- The course structure has been implemented for the first time in summer 2013. Thus there is not a lot of empirical knowledge and research on this course.
- The students have been asked directly if they were motivated by a special activity or if this activity helped them to learn academic content. As students may solely remember the AHA-moment and may not be aware of the specific effects of different course elements if they are asked immediately after the course, the used analytical method (direct interrogation) only displays the perceived effects and not necessarily the truth. Using an indirect method to check quantities such as knowledge and motivation among different test groups leads to a more solid outcome.

**Comparison of ENGR14 and GEP+TUTOR**

In general the review of isolated instructional methods or course elements in the reality is a challenge as those methods are usually mixed in course design. Thus tracing a visible effect back to one specific method is only possible by conducting a specific experiment. For example, regarding the bridge project it is not possible to decide if the positive influence on the learning process was caused by designing and calculating the bridge (problem-based learning) or building and testing it (hands-on learning). Furthermore, a number of influence factors such as motivation and emotion are not measurable as they are influenced by a large amount of other factors and are subjective perceptions. To exclude the personal variance it is necessary to interrogate large numbers of students.

The comparison between the courses and their evaluations is a challenge because for each course there has been a different evaluation process.

Finally, as the overall conclusions are derived from the analysis of two courses, their significance is debatable.
6 Conclusion

This work is an analysis of the influence of hands-on experiences on the learning process of engineering students and its application at Stanford University and Technical University of Munich.

In the first part of the work the basic structure and functionality of the human brain are analyzed neuroscientifically with a focus on the learning process. Learning is nothing but the change of synaptic connections between neurons in the human brain. This change is called neuroplasticity and is affected by different factors such as attention, motivation, and emotion. Furthermore, the way how information is stored in the human brain depends on the way how the information is learned. This effect is called Do-Effect. Based on the analysis of the influences on the learning process eight requirements for a beneficial learning environment are deduced, which can be applied in course design:

1. Addressing multiple senses and involving the body
2. Creating surroundings that foster attention and concentration
3. Creating positive emotions
4. Desisting demotivation
5. Emphasizing social interaction
6. Letting students work on their own ideas and in their own interests
7. Challenging students, creating flow
8. Integrating academic content into a superior context

Finally the instructional method Hands-On Learning (HOL) is introduced, defined and reviewed by means of the established requirements. The review of the definition shows that HOL can fulfill, depending on the specific implementation, every single requirement for a beneficial learning environment and thereby theoretically facilitates the neuronal learning process. It also helps students to structure the isolated academic contents from lectures to apply their knowledge creatively on new complex problems working under real life conditions.

Consequently, from a neuroscientific and psychological point of view hands-on learning is academically a reasonable instructional method.

The second part focuses on the application of hands-on learning to evaluate empirically if the findings from the theoretical analysis prove themselves true in.

In chapter 3 on the one hand five exemplary courses which contain HOL from Stanford University and Technical University of Munich (TUM) are introduced. The variety of possibilities for the implementation of HOL raises the awareness that it is not a universal standard concept but an idea that has to be individually fitted to every case of application regarding the specific goals, content and resources. In general there are two kinds of hands-on application in the introduced courses: Continuous labs, that are lined up to lectures and in which academic knowledge is applied practically, and projects, which can include teamwork...
and a comprehensive design tasks.

On the other hand chapter 3 contains a collection of experiences and lessons learned that were made frequently by different instructors in different courses at Stanford University and TUM. It comes out that there are a number of critical factors (e.g. class size, funding, resources), which decide about success and failure of HOL applications. In comparison to other instructional methods such as lectures or tutorials hands-on applications require a lot of resources (e.g. staff, time, access to workshops) and thus funding. Only if the necessary conditions are fulfilled HOL is an appropriate approach. Consequently, the decision for or against HOL has to be made carefully and individually for each course.

In chapter 4 two different courses are analyzed in detail regarding their content and structure and the course elements in which the hands-on approach has been applied. The first course is ‘ENGR14: Introduction to Solid Mechanics’, an engineering fundamentals course from Stanford University, the second course is ‘GEP: Grundlagen der Entwicklung und Produktion’, a fundamental class for mechanical engineering students at TUM. It comes out that in ENGR14 labs and projects are mixed and there is a high variety of different mixed instructional methods. In GEP there is a project, in which students have to develop their own product, and a final competition, in which about ten teams can build their prototypes.

Following this, different course reviews that were taken on ENGR14 and GEP are analyzed to obtain the effect, which the hands-on elements had on the student learning process and overall experience. It turns out that HOL can increase positive emotions and motivation and especially improve engineering thinking and comprehension and engineering practice skills. Nevertheless, there are critical factors such as the class size, access to material and workshops, and the availability of resources which have to be considered in course design.

At last, recommendations for ENGR14 and GEP are deduced based on the findings of part one and two of the work regarding the use of hands-on learning and the overall course structures.
7. Outlook

This work shows that the hands-on approach on learning contains different elements (such as solving real, complex problems by practically applying academic contents or using multiple senses by interacting with physical objects) which directly or indirectly support the learning process of students. The analysis of different implementations showed, though, that HOL is not suitable for every course and every goal but that it depends on the implementation (level of HOL, operational methods, etc.), the structure and underlying circumstances of the course, whether and, if so, which level of hands-on learning is appropriate. The concrete effect of a hands-on element in one course depends on a number of factors such as the instructional set-up of the course, the supervision by teaching staff, the rewarding system and the access to different resources and facilities.

To be able to isolate and determine the effect of single instructional elements on the learning process of students, I suggest conducting a series of short-term studies that compare a number of student groups: One control group that is taught with a set of traditional methods and problem-based approaches and a number of test groups that experience the same course elements as the control group plus an additional hands-on part. The difference between the hands-on elements within the test groups has to be reduced to one single aspect such as the level of HOL or teamwork vs. single person working. That enables a differentiation between the direct effects of PBL, HOL and other methods and allow a valid assumption about the immediate effects of HOL. Using indirect methods to test the dependent variables such as knowledge or motivation ensures the exclusion of individual perceptive differences.

Furthermore, I suggest conducting a long-term study with a similar setup: A control group that is taught in a traditional way, one test group with a focus on problem-based learning and another test group with a focus on hands-on learning. Evaluating aspects such as motivation, theoretical skill level, engineering practice skill level and their linking to different courses over a period of several years, from the beginning of a study program until a settled employment, results in a reflected assessment of the instructional methods. A long-term evaluation shows if students are indeed more motivated by PBL and HOL than in traditional courses, if they learn more and if their creativity and entrepreneurial thinking is increased over a longer period of time. As quantities such as motivation and emotion are subjective, it is necessary to interrogate a large number of students to exclude personal impressions and get universal results. Moreover, when different courses are supposed to be compared, it is necessary to apply the same evaluation process to receive comparable data.

As there are more examples for the implementation of HOL, one should also extend the analysis of existing hands-on courses and specific hands-on elements. I especially suggest to not only analyze successful examples but also bad practices, where HOL did not have the desired effects, to find out the reasons for the failure.

Regarding the neuroscientific knowledge about the learning process research has to be continued to detect all mechanisms in the human brain and the specific effects of different hormones and other substances as there might be a way to improve or facilitate the learning process by the external addition of those substances.
At last, this work was centered on engineering students. According to LEIFFER & BERGLUND (2013) engineers are likely to be categorized as active learners rather than reflective learners. Thus the question arises, if the influences introduced in this thesis and other studies are also valid for other groups with varying areas of studying and different age.
Attachment

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# A1 Interview Lists

## A1.1 Stanford University

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
</tr>
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<tbody>
<tr>
<td>Barton, John</td>
<td>Lecturer and Director of the Architecture Program</td>
</tr>
<tr>
<td>Beach, David</td>
<td>Teaching Professor and Director of the Product Realization Laboratory (PRL) and co-Director of the Stanford Alliance for Innovative Manufacturing</td>
</tr>
<tr>
<td>Beiker, Sven</td>
<td>Lecturer and Executive Director of the Center for Automotive Research at Stanford (CARS)</td>
</tr>
<tr>
<td>Burnett, William</td>
<td>Consulting Assistant Professor and Executive Director of the Design Program</td>
</tr>
<tr>
<td>Carryer, Ed</td>
<td>Consulting Professor and Director of the Smart Product Design Laboratory (SPDL) in the Design Division of Mechanical Engineering</td>
</tr>
<tr>
<td>Chen, Helen L.</td>
<td>Director of ePortfolio Initiatives at the Office of the Registrar and Research Scientist at the Designing Education Laboratory</td>
</tr>
<tr>
<td>Cutkosky, Mark R.</td>
<td>Professor and Director of the Biomimetics and Dexterous Manipulation Laboratory (BDML)</td>
</tr>
<tr>
<td>Dreissigacker Kohn, Marlo</td>
<td>Lecturer and manager of the Product Realization Lab's Room 36 student workspace and project laboratory</td>
</tr>
<tr>
<td>Eaton, Lea</td>
<td>Student and Researcher at the Designing Education Laboratory</td>
</tr>
<tr>
<td>Goodson, Kenneth</td>
<td>Professor and Chair of the Department of Mechanical Engineering</td>
</tr>
<tr>
<td>Hatch, Mark</td>
<td>CEO of TechShop</td>
</tr>
<tr>
<td>Hildemann, Lynn M.</td>
<td>Professor of Environmental Engineering and Science</td>
</tr>
<tr>
<td>Kenny, Thomas W.</td>
<td>Professor and Director of the Micro Structures and Sensors Laboratory</td>
</tr>
<tr>
<td>Leifer, Larry</td>
<td>Professor and Director of the Center for Design Research (CDR)</td>
</tr>
<tr>
<td>Milroy, James Craig</td>
<td>Senior Lecturer and Manager of the Product Realization Laboratory (PRL)</td>
</tr>
<tr>
<td>Mitchell, Reginald E.</td>
<td>Professor and Director of the High Temperature Gasdynamics Laboratory (HTGL)</td>
</tr>
</tbody>
</table>
17 Benjamin Packer Lecturer for Professor Daphne Koller
18 Schar, Mark Lecturer and Researcher at the Designing Education Laboratory
19 Schmutte, Kelly S. Lecturer at the Hasso Plattner Institute of Design
20 Seelig, Tina L. Professor of the Practice and Executive Director of the Technology Ventures Program
21 Sheppard, Sheri Professor, Director of the Designing Education Laboratory (DEL) and co-director of the Center for Design Research (CDR)
22 Smith, Robert Emery Director of Technology Service

**A1.2 Technical University of Munich**

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
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</thead>
<tbody>
<tr>
<td>1 Prof. Baier, Horst</td>
<td>Chairholder at “Lehrstuhl für Leichtbau”</td>
</tr>
<tr>
<td>2 Barth, Eric</td>
<td>Leader of the model making shop at „Lehrstuhl für Landschaftsarchitektur und industrielle Landschaft“ and contractor of the technical center (workshop) at „Fakultät für Architektur“</td>
</tr>
<tr>
<td>3 Biechl, Florian</td>
<td>Master mechanic at „Lehrstuhl für Fahrzeugtechnik“</td>
</tr>
<tr>
<td>4 Darnhofer, Erwin</td>
<td>Master mechanic at „Lehrstuhl für Fahrzeugtechnik“</td>
</tr>
<tr>
<td>5 Dr. Diermeyer, Frank</td>
<td>Senior engineer at „Lehrstuhl für Fahrzeugtechnik“</td>
</tr>
<tr>
<td>6 Distel, Fabian</td>
<td>Research assistant at „Institut für Werkzeugmaschinen und Betriebswissenschaften“</td>
</tr>
<tr>
<td>7 Glasl, Franziska</td>
<td>Trainer at „Zentrum für Sozialkompetenz- und Managementtrainings</td>
</tr>
<tr>
<td>8 Prof. Lindemann, Udo</td>
<td>Chairholder at “Lehrstuhl für Produktentwicklung”</td>
</tr>
<tr>
<td>9 Michailidou, Ioanna</td>
<td>Research assistant at „Lehrstuhl für Produktentwicklung“</td>
</tr>
</tbody>
</table>
A2 Questionnaires

A2.1 Stanford University

Questionnaire Stanford University

Goals:
- Definition of Prototype
- Role, function, methods and examples of physical prototyping in industry and at university (research and education)
- Goal, Content/Structure, Facts (time, # students), teaching methods (theory, practical application, intent) of classes
- Needs for courses (facilities, TAs, coaching ...)
- Facilities for practical application in Stanford
- Pros/Cons of the current educational system / lessons learned and experiences
- Wishes for the future
- Differences between Stanford and other universities in the US
- Find out the role of TechShop
- Further contacts to programs/facilities and literature

Questions:

Introduction:
- Few sentences: Who are you? What is your background?
- What is your current position and task at Stanford? (Education/Courses? Research?)

Basic understanding of prototyping:
- Can you give us a short personal definition of a prototype?
- Which role does prototyping in general and physical prototyping play in your field- both in industry and university?

Education and university:
- Can you give us a short summary of the goals, content and teaching methods of your classes?
- Which resources do you need for your classes (human, facilities)? Who is in charge of the facilities and who has access to them?
- What is the role of the d.school (Hasso-Plattner Design School) and PRL (Product Realization Lab) in engineering education at Stanford?
- What are the advantages of the teaching methods and infrastructure at Stanford? Do you see any disadvantages?
- If you had a wish for improving education and infrastructure at Stanford, what would it be?
- Is it possible to observe your facilities?

Others:
- Where do you see the main difference between Stanford and other universities?
- Is there any connection between Stanford and TechShop?
- Do you have further contacts or literature for us?
- What is your mission?
A2.2 Technical University of Munich

**Questionnaire TUM**

**Goals:**
- Raising awareness of our work and create possible collaboration
- Definition of Prototype
- Role, function, methods and examples of physical prototyping in industry and at university (research and education)
- Goal, Content/Structure, Facts (time, # students), teaching methods (theory, practical application, intent) of classes
- Needs for courses (facilities, TAs, coaching ...)
- Detailed information about conditions (accessibility) and equipment of the used facilities
- Pros/Cons of the current educational system / lessons learned and experiences
- Find out if and how TechShop can fit into the current concept
- Further contacts to programs/facilities and literature

**Questions:**

**Basic understanding of prototyping:**
- What are physical prototypes in your field and how are they used in your program/workshop?

**Education and university:**
- How is physical prototyping used in education for students?
- What are the facilities/shops used for prototyping in your program?
- What equipment is available?
- Who is in charge of the facilities?
- Which groups are using them (students, staff, firms, founders)?
- What are the conditions for students (accessibility)?
- Who is running and financing them and what is the connection to the department?
- Are students working in teams/projects?
- How do you grade your students?
- How is the relation between theory and practical application in your program?
- What is good/bad about the current system?

**Improvement possibilities for the department:**
- How could the program be improved (e.g. by TechShop)?
- Which requirements had to be fulfilled, that you use the prototyping center in your program?

**Next steps:**
- Are you interested in the outcome of the thesis and want to get involved in possible collaborations with the new TechShop?
- Do you have any further contacts/material that could be valuable to us?
A3 Survey on GEP+TUTOR

Q1 In der Werkstatt welches Lehrstuhls hast du mit deinem Team euren Prototypen gebaut? Lehrstuhl für ...

Q2 Hast du selbst handwerklich gearbeitet?

☐ Ja, aber nur mit Handwerkzeug
☐ Ja, auch mit industriellen Werkzeugen (z.B. Drehbank, Fräse, Schweissen)
☐ Nein, weil ...

Q3 Ordne bitte die verschiedenen Veranstaltungsteile nach ihrem Spaßfaktor (1 = hat am meisten Spaß gemacht, 3 = hat am wenigsten Spaß gemacht).

____ Vorlesung
____ GEP-Projekt (Methodische Anwendung)
____ TUTOR-Wettbewerb (Praktische Umsetzung)

Q4 Ordne bitte die verschiedenen Komponenten nach ihrem Motivationsfaktor (1 = hatte den größten Einfluss auf meine Motivation, 8 = hatte den geringsten Einfluss auf meine Motivation).

____ Vorlesungsinhalte
____ Lehrpersonal
____ Tutoren
____ Arbeit im Team
____ Methodische Anwendung
____ Arbeit an EIGENER Idee
____ Praktische Umsetzung
____ Wettbewerbssituation
Q5   Hatte die Methodische Anwendung im Rahmen der Postererstellung einen Einfluss auf ...

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<td>... deine Motivation für andere Veranstaltungen und das gesamte Studium?</td>
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Q6  Hatte die physikalische Umsetzung des Produkts im Rahmen des Wettbewerbs einen Einfluss auf...

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Q7  Was hat dir an der Gesamtveranstaltung GEP (inkl. GEP-Projekt und TUTOR-Wettbewerb) besonders gut gefallen, insbesondere im Vergleich zu anderen Vorlesungen?

Q8  Was hat dir an der Gesamtveranstaltung GEP (inkl. GEP-Projekt und TUTOR-Wettbewerb) nicht gefallen, insbesondere im Vergleich zu anderen Vorlesungen?
Q9 Hast du Verbesserungsvorschläge für die Gesamtveranstaltung GEP (inkl. GEP-Projekt und TUTOR-Wettbewerb) oder einzelne Veranstaltungsaspekte (z.B. Struktur, Lehrmethodik, Inhalte, ...)?

Q10 Würdest du dir während des Grundstudiums mehr Vorlesungen mit Projektarbeit (Anwendung) und Hands-On Elementen (praktische Umsetzung) wünschen?

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<tr>
<td>Projektarbeit</td>
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<tr>
<td>Hands-On Elemente</td>
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</table>

Q11 Welche Anteile würdest du den einzelnen Instruktionselementen bei der Neukonzeptionierung eines Grundlagenkurses geben (in %)?
A4 References


