Sensemaking in Construction; Comparing Learning Situations

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ABSTRACT

Developments in student learning, academic cultures and professional practice have placed education in universities for Architecture, Design and the Arts (ADA) and more specifically its teaching of engineering sciences, under review. Growing up in an environment of increasing complexity, today's student is largely relies on a trial-and-error approach in learning. As a result, a shift of the student learning preference towards action and experimentation is notable.

At the same time professional design practice is operating in an increased multi-disciplinary complexity, requiring designers to rely more on a profound understanding of disciplinary logics than a recollection of simple facts. However, explicit teaching styles based on deductive education and simplified problem solving, are often still favoured today. These teaching styles contrast with the student learning preferences and the required competences for the students' future practices.

Based on these observations, the authors' research aims to develop structured situations for experience-based learning in the context of construction education at ADA universities. By using workshops and construction experimentations, a profound understanding of structure and construction is pursued through a practice of making on the one hand, and instruction and theoretical reflection on the other.

In order to measure the effectiveness of experience-based learning, two learning situations are designed, discussed and compared within the scope of a structural education workshop. This paper describes the design and characteristics of these learning situations in relation to acquisition of different types of knowledge. Further, the workshop set-up for the comparison of both situations and their influence on learning effectiveness is presented. Finally, the effect of the student learning preference on the workshop outcome is examined.

Keywords: *Design Education, Engineering Sciences, Pedagogy, Learner-Centred Education, Learning Styles, Learning by Doing.*

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INTRODUCTION

This paper is a part of the ongoing PhD research *Sensemaking in Construction* of the first author at KU Leuven, Faculty of Architecture. This research intends to design a structured learning situation to support an acquiring of relevant and effective knowledge in construction science at Architecture, Design and the Arts (ADA) universities. In the proposed approach, the learning goals aim manage and understand ill-defined construction problems on the one hand, and handling of complex construction systems on the other. In order to reach these goals, complex problem-solving activities and sensemaking strategies, as discussed in cognitive psychology, are used as a starting point for the design of tools and strategies for implementation in design and design education.

LEARNING AND TEACHING ENGINEERING SCIENCES

This paper combines knowledge from multiple disciplines in order to provide a comprehensive and holistic understanding of learning and teaching in construction education at ADA universities. To frame the problems and challenges correctly, this section provides a brief overview of current conceptions on student learning characteristics and science education, and then connects these conceptions to multi-disciplinary practice in general and the design work field in specific.

Student Characteristics

Since the start of the current millennium, many writers and researchers have done their utmost in order to characterise the current generation of learners and students. With a generation raised in a world that is different from the environment of previous generation, it is believed that today's students behave differently to learning and education methods than previous learners. Therefore rigorous research is conducted in the fields of cognitive psychology (Gagné, Yekovich and Yekovich, 1993), learning styles and learning inventories (Kolb and Kolb, 2005; Vermunt, 1994), and neurosciences (Zull, 2002) in order to adapt university curricula to the student's learning preferences and learning abilities (DiLullo, McGee and Kriebel, 2011).

The generation, born between the early 80's and the end of the previous millennium (Straus and Howe, 2000), is often stereotyped as the i-Pod generation, Nintendo generation, Generation Y, the ME ME ME Generation but is mostly referred to as the Millennials (Paine Schofield and Honoré, 2008; Trzesniewski, 2010). With the early personal computers being introduced in the early 80's, this generation of students grew up as so called "digital natives" opposed to the earlier generations called "digital immigrants" (Small and Vorgan; 2008). As a result of living in a digital environment, the Millennial students grew up in a culture of increasing simulation, increasing instability and increasing complexity which is believed to have great repercussion on their cognitive qualities, their perception, their behaviour and their actions (Turkle, 2004; Simon, 1996: 80).

Studies highlight different characteristics to stereotype this Millennial generation of students in generational theories. In some publications a great overlap in findings is presented (Straus and Howe, 2003; Wilson and Gerber, 2008; Considine, Horton and Moorman, 2009), in other cases the findings are erratic or even antithetic (DiLullo, McGee and Kriebel, 2011). In order to frame the discussion in this research, the characteristics as discussed by Paine Schofield and Honoré (2008) are used because of the focus on learning and education on the one hand, and their compatibility with competency-based learning and experience-based learning on the other. In this study, millennial students are believed to have a need for immediacy and they use a trial-and-error approach to problem solving. Furthermore, for students '*doing'* is more important than '*knowing'* and they are supposed to have a low boredom threshold. In addition, they value visual, nonlinear, virtual and collaborative learning, and prefer a constructive approach in learning.

Engineering Sciences Education

As a result of these changes in learning preferences of the current generation of students, the education of applied sciences has been placed under scrutiny over the last two decades (Rugarcia, Felder, Woods and Stice, 2000; Katsioloudis and Fantz, 2012).

The education of applied sciences traditionally aims at the transfer of knowledge through single-discipline, instruction-based (Mills and Treagust, 2003; Bar and Tagg, 1995) and teacher-centred (Weimer, 2002) delivery. In cognitive psychology and instructional design theories, various names are given to the knowledge resulting from this teaching. For reasons of simplicity we use the understanding of conceptual knowledge to refer to this explicit type of knowing. In this framework, conceptual knowledge is stored in the declarative memory which is a long-term memory knowledge of knowing that something is the case.

Consequently it is a type of knowledge that we can retrieve consciously. Furthermore it is a knowledge that is considered *static* (i.e. easily modified knowledge of which the passive basic units are quickly acquired), rather than *dynamic,* which provides us with automated basic skills and domain specific strategies in the form of competences, habits, priming and simple classical conditioning (Ashcraft, 2006:211-212; Gagné, Yekovich and Yekovich, 1993: 59-60, 218; Groome, 2014: 225-226; de Jong and Ferguson-Hesseler, 1996; Krathwohl, 2002). Conceptual knowledge provides us with an understanding in the form of facts, concepts and principles, which are used in the process of problem solving (Ashcraft, 2006:211-212; Gagné, Yekovich and Yekovich, 1993: 59-60, 218; Groome, 2014: 225-226; de Jong and Ferguson-Hesseler, 1996; Krathwohl, 2002).

Teaching conceptual knowledge, often starts with an instruction in general concepts and principles through lectures, articles and figures. The presented principles are then used in a step-by-step process to solve an exemplar problem. Finally, the student is presented a slightly altered problem and asked to solve it using the introduced step-by-step process. By reproducing the problem-solving procedure as introduced during the course, the student is able to respond to well-defined problems (i.e. tame problems) in line with the example discussed (Rittel and Melving, 1973; Hicks, 2004).

Opposed to this traditional teaching style in science education, stands the studio-centred (Kolko, 2005; Schön, 1987) or learner-centred (Weimer, 2002) situation. Such exercises emphasise on the acquisition of *implicit knowledge*. For reasons of simplicity as discussed earlier, in this section we use the term *procedural* knowledge to refer to this implicit type of knowing. In contrast to conceptual knowledge, procedural knowledge is stored in the procedural memory which is a long-term memory of knowing how to do certain things. It is a type of knowledge that can alter our thoughts and behaviour without us being consciously aware of it. This knowledge is *dynamic*.

The studio exercise starts with a design task or a design problem, framed in a complex realworld context. Then information and techniques are presented to sketch the design task at hand. As an alternative, students are challenged to develop their own techniques instead. (Prince and Felder, 2006; Ashcraft, 2006:211-212; Gagné, Yekovich and Yekovich, 1993: 59-60, 218). By being able to respond to real-world problems through self-developed problem-solving approaches, the student is able to respond to ill-defined problems (Hicks, 2004), also known as wicked problems (Rittel and Webber, 1973).

Multi-disciplinary Practice

As a result of a strive for structural integrity in architectural design (Leach, 2004), and a new relation between universities and industry (Gibbons et al., 1994), design practice has become increasingly more multi-disciplinary over the last decades. For reasons of simplicity we will characterise all collaborations involving multiple disciplines as multi-disciplinary.

In multi-disciplinary design in general and architectural design in specific, multiple disciplines collaborate in an integral way by combining knowledge and domain-specific strategies: architects are involved in structural design and engineering, while engineers are involved in architectural design from the conceptual phases to its construction. Therefore all participating parties are involved in problem-solving activities which make them rely on procedural design knowledge to a greater extent (Leach, Turnbull and Williams, 2004).

With practice and industry operating in a turbulent and fluid era (Cameron and Tschirhart, 1992; Bauman, 2000) education is searching for new roles in order to adapt to the challenges of the post-industrial environment (Becher and Trowler, 2001). Therefore the strict disciplinary engineering education, depending on content driven programs, should be extended in order to relate to these changes (Fruchter, 2001; Mills, 2003; Andersson and Andersson, 2006). Consequently, a shift from an education aiming at the transfer of mere conceptual knowledge to a competency-based education, including procedural knowledge and problem-solving qualities is of utmost significance (Barr and Tagg, 1995).

DESIGNING A LEARNING SITUATION TO ACQUIRE DYNAMIC KNOWLEDGE

Experience-based learning, whose early developments are often attributed to Dewey (Dewey, 2009; 1997; Andresen, Boud and Cohen, 1999), and learner-centred teaching, as introduced by Maryellen Weimer (2002), have proven great effectiveness in numerous studies (Pomales-García and Liu, 2007; Ebner and Holzinger, 2007; Fruchter, 2001; Bhattacharjee, 2014, Millsand Treagust, 2003, Andersson and Hammar Andersson, 2006). In experience-based learning in general and learner-centered paradigms in specific, students construct their own knowledge in practice (i.e. in contrast to teacher-centred paradigms, in which knowledge is transmitted from the professor to the learner). Consequently, the learner is no passive reader but actively involved in his/her own education and learning. This active approach involves learning by trial-and-error with an emphasis on doing before reflecting, which makes this paradigm very accessible for Millennial students.

Learning Situations

In learner-centred education, experience-based workshops and practicums can be a playful and creative way to introduce and explore topics and themes. In the act of making or building, learners interact with materials and products in a less formal way in order to acquire knowledge on their own terms and at their own pace.

To learn how to deal with the wicked problems of design, workshops and games can be applied to make the relationships among concepts and theories explicit and more understandable: the interaction with fundamental construction problems can be used to examine concepts more deeply and to test ideas and hypothesis more effectively in order to construct technical competencies (Dewey, 1933).

The workshop as a game is introduced in the book *Gamestorming* by Gray, Brown and Macanufo (2010). As a significant part of the gamification movement, the book introduces game thinking and game mechanics as a strategy to engage participants in processes like creative thinking, divergent thinking (Guilford, 1957), and design thinking (Cross, 2006; Cross 2011).

Gamestorming provides various insights in creative processes by comparing it with game structures. This leads to a development of strategies which make these creative processes accessible to a broader audience than the environment of academic designers. The presented research applies these game strategies in teaching to connect the creative processes of design with the learning preferences and learning qualities of the Millennial student. By presenting the workshop or

FIGURE 1: Original Learning Situation of the Game World

practicum as a structured game or a series of puzzles, the student may enter familiar ground and engage more easily.

In *Gamestorming*, the game world is introduced in a five-step process, which is directly integrated here below into the workshop environment of the research. First, the learning goals are set and clarified by the course leader. In this stage, the goals are not made explicit to the workshop participants. In the **introduction** (1) of the gamified workshop environment, the learning situation and the rules to play by, are set. Furthermore, the tools and materials to work with are introduced and goals are discussed occasionally. In the **opening** (2) of the workshop, the rules, materials and tools must be understood by the participants; the players have to understand what they represent and how they operate in action. In this phase, misconceptions and misunderstanding are to be eliminated in order to attain the learning goals as set. In the **exploration** (3) phase, the participant aims to realise the goals. In some cases these goals can be set in the introduction phase of the game, in other they can evolve from the explorative process. The world is **closed** (4) when the goals are achieved. By completing these steps the player acquires the learning goals (i.e. knowledge) (5) in divergent, explorative and convergent phases (Figure 1).

FIGURE 2: Preliminary Study of Learning Situation

FIGURE 3: Inductive Learning Situation

In a preliminary study by the first author, the original model of the game world was used in a workshop exercise at HKU Utrecht School of the Arts. In this exercise, students are asked to design a chair with a specific set of materials and products, and to provide construction drawings for it to be built. Then students are asked to exchange their construction drawings with another group of students, and to build the chair according to the drawings of the other group.

After this building exercise, students are challenged with a design exercise dealing with the materials, products, processes and connections as used in the construction workshop. During this design exercise students indicate that they are not able to complete this exercise successfully: the experience of the workshop exercise is insufficient for the providing adequate knowledge to students in order to finish the design exercise successfully.

In reflection on students' reactions, the original learning situation of the game world as presented in Figure 1, is therefore extended with a distinction between procedural and conceptual knowledge. Furthermore, the exploration phase, which is the main interaction phase of the learning situation, is further refined by the interactions 'activity' and 'participation' as described by Illeris (2003).

In retrospective, students seems to acquire mostly procedural knowledge of furniture construction while making the piece of furniture in the construction workshop: knowledge is stored in the student's memory but without the student being consciously aware of it and being able to make it explicit. Then when students are questioned in the following design exercise with an interaction requiring conceptual knowledge and not procedural, they are unsuccessful in completing the task.

In order to support both the acquisition of procedural knowledge and the transfer of conceptual knowledge, two different modulations on the original learning situation (Figure 1) are made: the *Inductive Learning Situation* (Figure 3) and the *Deductive Learning Situation* (Figure 4). In the Inductive situation, students start with the activity of making a construction after which the construction is presented to the course leader. At this point, the work is still framed in the context of procedural or implicit knowledge. Then students participate in a reflective dialogue

FIGURE 4: Deductive Learning Situation

with the teacher, discussing the construction model with an emphasis on conceptual understanding. By doing so, they become consciously aware of the conceptual knowledge as studied in the act of making.

In the deductive situation, students are firstly instructed in conceptual knowledge of the building exercise by the interaction of knowledge 'transmission' (as described by Illeris,2003): the correct domain-specific knowledge and vocabulary are discussed and methods for effective making and various construction approaches are presented. They then start the physical building exercise.

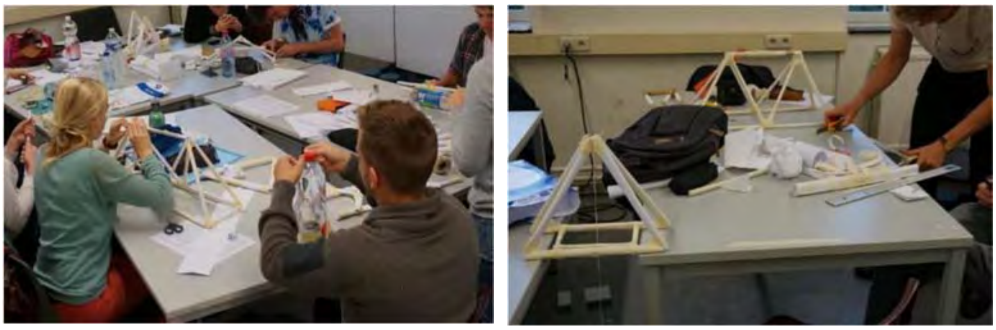
In this learning situation the transmitted conceptual knowledge of the building exercise is then framed within the procedural knowledge through the student's reflecting on and experiencing of the concepts in practice.

WORKSHOP CASE STUDY

The learning situation as discussed in the previous section are investigated in a workshop as part of a structural-design course at KU Leuven, Faculty of Architecture in Belgium. The group of second bachelor interior architecture students participating in the workshop consists of 61 students in total: 13 male students and 48 female students. The workshop involves two building exercises, covering multiple aspects of structural mechanics and structural analysis.

FIGURE 5: First building exercise

FIGURE 6: Second building exercise



In the first exercise, students are requested to build a paper tower. In this exercise, structural concepts, such as horizontal stability and buckling, are introduced to students. The building material is limited to 20 sheets of paper, tape and glue. In this exercise, the challenge is to design and build a tower as high as possible, which is able to carry the load of a 1.5 litre bottle filled with water on top of it. The time limit for design and construction is 45 minutes.

In the second exercise, the students are required to build a span between two tables. In this exercise, structural concepts, such as bending, compression and tension, are introduced to students. The span is to be placed freely on the table: it cannot be connected to the table to avoid a structural design only under tension. In this exercise, the challenge is to design a span as large as possible, able to carry a load of a 1.5 liter bottle filled with water, connected by a rope to the middle of the span. Like the first exercise, the time limit for design and construction is 45 minutes.

Research Design

In order to test and measure the effects of the inductive and deductive learning situations on student behaviour and learning outcome, a panel model was used (Selig and Little, 2012). In this model we aim to examine the structural relations in a repeatedly measured longitudinal study. In order to construct internal validity, a cross-lagged panel model (Kenny, 1979) is designed, combining within-subject and between-subject set-ups (Field, 2013; Sani and Todman, 2006). This enables us to measure two within-subject studies in a between-group model. Consequently, in order to internally validate the findings, effects of the first group in the first part of the study are compared with the effects of the second group in the second part of the study.

In the cross-lagged panel model, students are divided into two groups. Both groups are asked to perform the two building exercises in succession. The first group of students perform the first exercise according to the deductive learning situation. These students then perform the second exercise according to the inductive learning situation. For the second group, the sequence of the learning situations are switched: they start with the inductive situation and continue with the deductive situation.

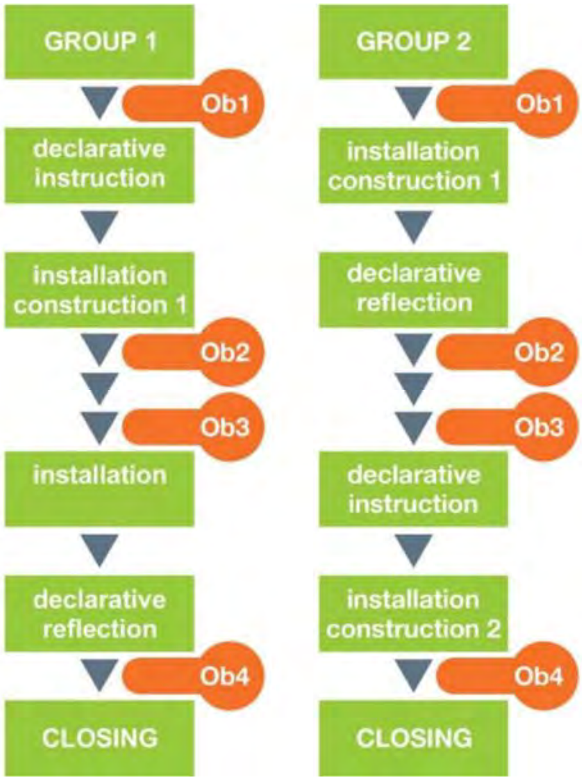


FIGURE 7: Cross-lagged panel model for workshop data collection with four observation points

Different students have different ways of learning. For instance, some students prefer being active and doing things, while others like to sit still, watch and think. In order to obtain two comparable groups with respect to these learning preferences, Kolb's Learning Style Inventory (LSI) Version 3.1 was used (Kolb and Kolb, 2005). In this inventory, students are asked a series of questions that discuss their specific learning characteristics. The outcome of the inventory is measured on two axis. The way we process information is situated on the horizontal axis: the learning modes active experimentation (AE) and reflective observation (RO) are situated here at both ends. The way we perceive information is situated on the vertical axis: concrete experience (CE) is placed on the one side of the scope and abstract conceptualisation (AC) on the other (Richmond and Cummings, 2005; Demirbas and Demirkan, 2007). The combination of the highest score of each scale results in a *converging* (AC/AE), *diverging* (CE/RO), *accommodating* (CE/AE) or *assimilating* (AC/RO) learning preference.

In order to measure the effects on behaviour, learning outcome and usability, multiple sources of data collection are used. The first source is a four-step survey (i.e. Ob1 to Ob4, Figure 7), in which data is collected to measure learning effects at different moments in the longitudinal study. In each observation before and after the building exercise, students answer five questions with regard to his/her structural understanding in relation to the building exercise at hand. In these questions, the student is shown a picture of a structural model related to the exercise, followed by a statement about a change in this model. Such a change could be an extension or a subtraction of parts of the structure. In the proposed statement, a structural quality is expressed (e.g. the structural behaviour will not change after removing a specific part). Student are then asked to rate this statement by 0, 2, 4, 6, 8 or 10 points (0 meaning ‘I do not agree at all’ and 10 meaning ‘I completely agree’). The difference in score (i.e. score difference) between the right answer (i.e. 0 or 10) and the student’s rate is then used to measure the conceptual understanding of the student.

To calibrate the cognitive difficulty of each statement, all statements are presented to 27 third year bachelor students of the interior architecture program. These students followed the same structural education of the students under investigation. For each statement the score difference of the investigated student is then compared with the average score difference of the control group: this enables us to measure the student’s evolution in structural understanding before and after the exercise, despite variations in difficulties of the proposed statements.

The second source, is the *success reflection method* of Benammar et al. (2001) which is used to reflect on the student experiences. In this method, a group-wide reflection is conducted, using a multiple-step process. In the first step, students appoint factors that have added to successes during the workshop and elaborate on them in couples. In the following steps, factors are collected and grouped in themes. Then, one theme is selected for a group discussion. Finally, plans are made in order to make this success-theme a constructive part of future practice or studies.

The final source is a survey, used at the end of the workshop. This survey elaborates on usability, with respect to usefulness, effectiveness, learnability and likeability (Jeng, 2005). In this survey, students are asked questions about the outcome of the LSI, the likability of the different learning situations and the qualities of learning in practice.

WORKSHOP ANALYSIS

In this workshop-study, multiple aims and directions are reviewed and discussed. First, we will discuss the learning style preference of the Millennial student as discussed in the previous section. Here, we will look at possible correlations between learning style preference and the learning improvement of the longitudinal observation points. In addition, we will look at possible correlations between learning style preference and workshop outcome. Secondly, we will discuss the outcome of the student surveys and the success reflection.

Comparing Learning Style Preferences in Relation to Longitudinal Learning Improvements

In the outcome of the Learning Style Inventory, 47% of the students preferred a converging learning style, 28% preferred an accommodating learning style, 21% preferred an assimilating learning style and 2 % preferred a diverging learning style.

FIGURE 8: Construction models from exercise 1

FIGURE 9: Construction models from exercise 2

According to the learning improvements, measured by the observation points of the crosslagged panel model, 36% of the students show progress in structural understanding in both parts of the workshop and only 10% show no progress in none of them. 54% of the students show progress in one of the two parts with an equal distribution.

The subdivision into four groups of learning style preferences (i.e. converging, diverging, accommodating and assimilating) according to the outcome of the LSI, shows no significant correlation with cognitive preferences in the tested learning situation. In one group very distinct differences could be noticed in learning improvements of the students in both parts of the workshop, and in both learning situation. This seems to indicate that students do have a personally preferred learning situations, but that the outcome of LSI does not group these students accordingly.

Student Surveys and the Success Reflection

The outcome of the success reflection describes three groups of success-themes. The first group of success factors discusses the use of physical models in education. In this group, qualities of direct feedback on actions in models are emphasised. The second cluster is related to the qualities of learning in the act of making. Here, factors like creativity, experience of making and the different approaches to making are discussed. Furthermore, the students appreciate the limited timeframes of the exercises: the short sprints in making are experienced as an active energy. The third theme emphasises the structured material reflection and construction design. This reflection in a material context brings forward new insights and new thoughts on structure and form.

The most appreciated cluster of success factors is the third theme, the quality of reflection. In order to make this quality an active part in future projects, students indicate different approaches using reflection by use of models as active parts of the design process. Furthermore, reflection on models is adopted as a strategy in order to look at concepts and ideas in a critical way.

The findings of the success reflection are endorsed by the outcome of the general survey. In this survey three quarters of the students express their love for learning by doing and working in groups. Students describe it as “nice to learn by doing to understand the theory” and “finally we really get to think about an exercise”.

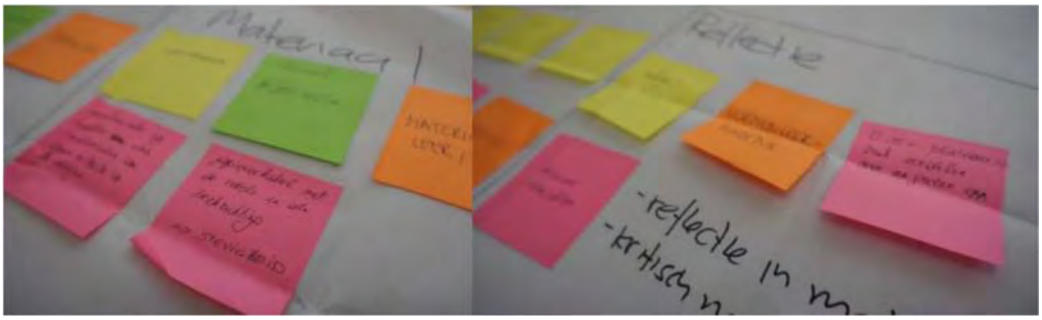


FIGURE 10: Success Reflection Clusters

In order to make a clear distinction between the two learning situations tested, no support or reflection by the course leaders on the student's work was provided during the exercise. Consequently, only the reflection part of the inductive learning situation was appointed as an opportunity to respond to the results in a more general manner. In the general survey, students indicate that personal feedback on their work was missing in the workshop. In reference to similar workshops, students indicate that a personal discussion or reflection is an important part of the workshop in order to understand the structural logic of the constructed models. Furthermore, they even suggest to introduce film registrations of this reflection moment for later consultation: as a result of time pressure, the reflections are often short and compact and therefore sometimes hard to follow. By having access to film material, students indicate that they are able to study the material at a later point in time, to fully comprehend the model as discussed.

CONCLUSIONS AND FUTURE PROSPECTS

With regard to learning preference, about three quarters of the participating students preferred an active approach to learning over a reflective variant. In the results of the survey and the success reflection, the students appreciated the team oriented and collaborative way of learning. Furthermore, students preferred the trial-and-error and structured workshop approach to teacher-centred learning. This outcome emphasises the learning preferences and learning qualities as described by of Straus and Howe (2003) and Paine Schofield and Honoré (2008). However, it is unclear how to extrapolate the study: on the one hand, the preferences of the Millennial student can account for the results of the study; on the other hand, the preferences of ADA students or even a combination of both, as discussed in the work of DiLullo, McGee and Kriebel (2011), can be a leading factor.

Both the Deductive and the Inductive Learning Situations proved equally effective in practice: an equal amount of students show to make progress in structural understanding in both situations, but also an equal amount show to make no progress in one of the two situations. The question remains if students have learning styles in correlation with these situations. Using LSI to determine differences in learning styles has however, not provided such correlation in the presented test.

In neither the learning results from the pre- and post-test observations nor the scores from the model review, significant differences in learning effects were found between the two learning situations discussed. However the survey questions, discussing the student preference for one of the models, showed a strong preference for the inductive model.

In the future, the dynamic and static qualities of the acquired knowledge will be tested. By a shift of focus of the study, different qualities of the knowledge acquired will be discussed. In this study, the correlation between dynamic and static knowledge will be tested in relation to the inductive and deductive learning situation.

FIGURE 11: Learning Situation for Understanding

Because no significant learning improvement was measured in the comparison of both learning situations, students' expressed preference is used for further development. In order to accommodate student requests for personal feedback and discussion, the inductive learning situation is extended by a transmission interaction (Figure 11). In this part students are supported in the transformation of procedural knowledge into conceptual knowledge by using domain specific vocabulary. When students become aware of the conceptual knowledge, discussed in the construction exercise, and when they are able to frame this knowledge into the domain specific vocabulary, we can speak of understanding.

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