A case study about supporting the development of thinking by means of ICT and concretisation tools

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Abstract: Improving learning and thinking in school has been an objective of the educational community for a long time. Computer applications and especially mind tools can be helpful in reaching this objective. Control software that operates a connected physical micro world and is used as a kind of mind tool, delivers possibilities to develop and support learning and thinking of pupils in school. We studied pupils’ thinking behaviour (thinking skills and habits of mind) by analysing the progressive discourse of pupils who solved problems using Techno-Logica control software in a hybrid micro world. We developed a first version of an observation instrument and tested its usefulness in exploring thinking behaviour. In this paper, we present the first results and prospective.

Keywords: control software; habits of mind; hybrid micro worlds; ICT; micro worlds; mind tools; Lego Mindstorms; technologica; techno-logica, technology; thinking skills.


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1 Introduction

According to Bereiter (2002), human cultures have arrived in the era of knowledge societies and knowledge economies. Therefore, we need new theories on learning, teaching and knowledge. In order to produce new expertise one needs to elaborate skills to acquire and process information. More and deeper understanding of the use of complex thinking processes (both critical and creative ones) is needed in order to build curricular lines congruent to subject matter domains, across mental skill repertoires and personality traits.

ICT offers many chances to find innovative ways of teaching and supporting cognitive development of learners. Kommers (2005) asserts that the continuous stream of new media and ICT applications is the main source for the evolution of education. Developing cognitive learning tools that instigate new pedagogical values; this is the challenge for the next coming years.

This study emphasises the importance of stimulating active learners in solving meaningful problems by means of ICT applications. The notion of mind tools seems to be crucial for studying modern ICT applications in innovative pedagogical contexts. Mind tools are the overarching class of learning support software that aims at activating (generic) learning and thinking skills (Jonassen, 2000; Jonassen et al., 2003). It also aims at articulating learning attitudes and habits of the learner’s mind (Costa, 2000).

A good teacher should not only manifest competences like instructing and testing pupils’ knowledge. Good teachers offer the pupils various opportunities to learn (collaboratively) by using gifts of modern technology. In spite of that, we know that ICT in its innovative sense is not easily adopted by teachers. Student teachers could well have an important role by the adoption and implementing of these new technologies (Bers et al., 2002; Slangen and Sloep, 2005). They are more accustomed to modern technologies and, as we experienced, they adopt the employ of ICT as a new educational technology more easily.

In this publication, a case study is described in which a student teacher used control software based on a concrete micro world to stimulate collaborative learning and thinking
A case study about supporting the development of thinking processes at the primary level with students of 11 and 12 years old. A Techno-Logica problem-solving task was offered to initiate discourse and active thinking behaviour. We developed an observation tool to collect data and gain more insights into thinking behaviour. Initially, we describe the position of learning and thinking in school and the role of mindtools, after that we analyse some previous research on the use of control software and concrete tools. Subsequently, we explain our case study and end up by presenting some preliminary results and conclusions.

2 Mind and tools in school

Learning and thinking are innate and intertwined qualities of a human being. People learn a lot spontaneously. However, sometimes learning and thinking are explicitly organised, e.g. in schools.

2.1 Learning: the role of schools

The challenging question is: does learning really need schools? In any case, it may be claimed that schools pretend to optimise the efficiency of learning.

Resnick (1987) asserted that schools aim at the development of higher-order thinking skills such as critical thinking, problem solving, reasoning, refining ideas, interpreting and creative applying of these skills. In addition, as we have stated that such skills are important tools in modern society. Schools should choose strategies that activate thinking processes leading to a rich knowledge base, form concepts and understanding, and strengthen the thinking behaviour in itself. However, many schools are not very successful in reaching these goals (Resnick, 1987; Boostrom, 2005). Despite the emphasis on the importance of the process of learning and thinking, many teachers still practice the teaching as a process of conveying factual knowledge in itself. Teachers expect the learner to accumulate and absorb knowledge.

Study of experts’ knowledge demonstrates the importance of the combination of having a large knowledge base of facts at one’s disposal and having it associated and organised around important concepts (Bereiter, 2002; Bransford, Brown and Cocking, 2004). We conclude that learning is more than gaining and reproducing declarative or procedural knowledge. It is the development of connected concepts and insights by using this (factual) knowledge. Learning can only be successful if it makes sense. An emphasis should be placed on learning with understanding. Schools should organise learning in such a manner that real understanding can develop.

Concrete learning could be very helpful in developing the better comprehension of fundamental insights. Children do often gain sudden understanding after visualising (concretising) abstract processes or problems. The benefit of learning by using real-world objects and/or context is often underestimated. For that reason, concrete learning should get more attention, but not only as a stepping stone towards abstract learning (Papert, 1993). Concrete learning should also have a powerful intrinsic value. Bereiter (2002) says:

“Understanding the problem may require understanding other abstract objects, but also requires some engagement with the real world phenomena that give rise to the theoretical problem. It is the same as with understanding a tool or a machine.”
Papert (1993) advises that teaching practice should change structurally. Schools should use the power of natural learning by favouring constructionism over instructionism. From a social constructivist perspective, learning is a process of personal development through constructing and reconstructing new and previously acquired knowledge in interaction with the other. Such processes can be initiated and mediated by using concrete learning objects and tools. Therefore, teachers should use these objects and tools to organise constructive learning experiences in school. By doing this, teachers have many opportunities to stimulate conscious and reflective learning. That is the main reason for the existence of schools.

2.2 A focus on activating thinking in schools

For many centuries, philosophers, psychologists and educationalists have been trying to map out processes and tenets of thinking by studying these very accurately and describing them in manageable terms (Bransford, Brown and Cocking, 2004). The gained insights should help the teacher realise that education should stimulate learners to think more effectively. The question is whether a classifying system of thinking behaviour should be converted to prescriptive teaching rules? This question already suggests that different categories of thinking behaviour can be converted into teaching modes. “A taxonomy can be invented to classify instances of thinking after they have occurred, but it cannot show us how to create these instances” (Boostrom, 2005). Resnick (1987) signals that thinking is teachable, but that there is no evidence that higher-order thinking can be learned by acquiring specific components. This means that teachers’ objectives should trigger thinking by continuously using appropriate activities rather than teaching thinking in isolated tasks. If we want to activate higher-order thinking that is more than memorising, pupils can only be activated in this way by confronting them with materials, situations or contexts they have never dealt with before (Boostrom, 2005). Based on theories of the neurobiology and brain-based learning, Kok (2003) described some implications for creating valuable learning environments. These environments should arouse realistic and holistic learning experiences in which pupils can be entirely wrapped-up. This implies offering complex tasks that stimulate a lot of thinking and that have a high degree of safety, challenge and active involvement.

We suppose that thinking is improvable. However, the question remains if we can identify generic thinking skills or if thinking skills are based on content and context. In other words, is thinking based on different skills or is it based on various kinds of dispositions? Experts are not just ‘general problem solvers’, they seem to solve problems by using a base of well-organised knowledge (Bransford, Brown and Cocking, 2004) and strategies. Experts do not only recognise easier relevant aspects of problems in new domains they also choose different starting points and ways of tackling problems than novices. We conclude that it is a fact that thinking needs context. Various contexts are needed for eliciting realistic prior knowledge. As Resnick (1987) says: “Good thinking depends on specific knowledge, but many aspects of powerful thinking are shared across disciplines and situations”. Facts or (organising) notions and former learned skills make it easier for an expert to think in specific situations in a more sophisticated manner.

Costa and Kallick (2000) described the relationship between thinking skills and habits of mind in a model composed of four concentric circles (Figure 1). In the centre circle, we see discrete thinking skills, such as comparing, classifying, recalling and etcetera. Nevertheless, these skills operate only within cognitive operations (the second circle)
which are larger and more complex strategies, such as problem solving and decision-making. The third circle that encompasses the previous two contains the habits of mind, which are characteristics of intelligently acting. The fourth circle contains states of mind, such as motivation, balance, and drives. The integrated thinking model (Iowa Department of Education, 1989) offers a more detailed picture of the relevant components of these two inner circles (thinking skills and cognitive operations). Cognitive operations (complex thinking processes) such as problem-solving, designing and decision-making, need on their turn thinking skills, like critical thinking (analysing, evaluating, and connecting), creative thinking (synthesising, elaborating, and imagining). Higher-order thinking skills such as critical thinking and creative thinking in succession relate to reorganising and generating knowledge. This higher-order thinking needs content/basic thinking (accepted knowledge and meta-cognition). Content thinking concerns facts, rules, skills, concepts, principles of the specific domain, etc. Basic thinking relates to simple learning to learn skills. Both approaches have in common the assumption that intelligent thinking is not a collection of separate skills but a complex interactive system.

The integrated thinking model (Iowa Department of Education, 1989; Slangen and Sloep, 2005) was composed to support educators in their work on developing curriculum and instruction. Teachers should use more opportunities (tools) to offer pupils complex and holistic tasks, to arouse and sustain their active thinking behaviour, keeping in mind the underlying components. We state that modern ICT-tools are well suited for this purpose. ICT-tools, like the ones we mention further on, are useful to generate motivating problem-solving and decision-making tasks in which learners can act intelligently, activate complex thinking processes and use skills such as critical and creative thinking. They function as teaching tools that empower thinking.

**Figure 1** Circles of relationship: relation model of thinking skills, cognitive operations (higher-order thinking skills), habits of mind and states of mind

2.3 Mind tools support thinking activities

It is the pupil, him or herself who learns or thinks and it is the school that should offer opportunities for good learning and thinking. Therefore, teachers, computers or books are just devices to activate or support these processes. Jonassen (2000) defines mind tools as “computer applications that require students to think in meaningful ways in order to use the application to represent what they know”. This indicates that not all computer applications or the use of these applications can be seen as mind tools. Such applications should at least trigger meaningful learning activities which can be defined as: active (manipulative/observant), constructive (articulative/reflective), intentional (reflective/regulatory), authentic (complex/contextualised) and cooperative (collaborative/conversational; Jonassen et al., 2003).

The last decade has shown a fast evolution in the development of ICT applications concerning the so-called micro worlds. Micro worlds are usually defined as software environments for creating virtual worlds in which objects and/or virtual actors can be controlled and/or programmed (incredible machine, Sims city and second life). In such worlds, a learner can navigate, make decisions, experience consequences and expand ideas. Often, micro worlds are limited simulations of real world situations. They are powerful mind tools that portray the dynamic relations of the content, and can be used to construct simulations or virtual models. All micro worlds have in common that they take the learner to a constraint (safe) environment where new constructions can be made while the system provides feedback to the learner.

We can also identify other kinds of micro worlds. The hybrid ones that combine control software with a real physical play world like Lego, Fisher Technics, Lazy, etc. Software applications like Techno-Logica and Lego Mindstorms are both control software applications that operate objects in a physical world (Figure 2). These software applications can be used as mind tools, which, from a constructionist point of view, activate higher-order thinking of pupils. Nevertheless, we should be warned. Bereiter (2002) supposes that: “if the only justification for an activity is that it is supposed to encourage or improve thinking, you should drop it and replace it with an activity that advances students’ understanding or that increases their mastery of a useful tool”. Mind tools, therefore, should be applied in a context that is worth in itself to learn from, about or with. The context, in which we situate the use of these hybrid micro worlds, is related to learning from content and concepts out of physics, technology and science. These contexts are motivating and offer the learner many opportunities to develop situated knowledge of the specific domain. However, if we really want to support curriculum and instruction with useful mind tools we have to know more about the characteristics and the contribution to teaching and learning of different kind of tools and tasks.
3 Research on micro worlds and concretisation tools

Lego Mindstorms, Techno-Logica and Empirica Control are all examples in which concretisation tools (concrete physical models) are controlled by means of icon-based control software. Lavonen, Meisalos and Lattu (2001) suppose that a visual programming tool based on icons is easier to be learned than a programming language based on text. The tools can be used in a more effective way, e.g. for learning concepts of physics. Learning a programming language is not the goal in itself.

We suppose that software that control concrete physical objects or models have some special features, which are very useful in learning. First, these tools stimulate pupils’ active thinking through using the concrete context of a technologic and scientific world. Secondly, they give rise to an increasing understanding of scientific and technological concepts and to logical thinking within these contexts. Thirdly, as our study showed, many opportunities are offered to provide practice in problem solving and generic thinking skills.

Krumholtz (1998), who uses Techno-Logic software in combination with technological construction material, found an increasing intuitive and formal understanding of concepts from physics, e.g. speed, acceleration, gravity, friction, force and balance. In various studies, the use of Lego Mindstorms has been supported. Bers et al. (2002) show us how Lego Mindstorms encourages the development of student-teachers’ technical fluency and how it is used to teach young children (Pre-K to 2) difficult concepts, e.g. that of a life-cycle. This way of handling Lego Mindstorms shows how its use is based on the four tenets of constructionism: learning by design, manipulating objects to think with, exploration of powerful ideas and self-reflection. Savage et al. (2003) describes a Problem-Based Learning (PBL) experience in robotics with non-technical third level students. The conclusion of this study was that the combination of constructionism, mind tools and discourse offers a great potential to promote higher-order thinking skills. We also noticed other promising experiences of cognitive, emotional and social learning of pupils and teachers in primary schools and
schools for special education through constructing robots and programming them with Lego Mindstorms (Eronen et al., 2002; Sutin, Virmajoki-Tyrväinen and Virnes, 2005; Kärnä-Lin et al., 2006).

Nevertheless, several results are less positive. Lavonen, Meisalos and Lattu (2001) studied 14 years old pupils in a learning environment based on physical hardware and the programming tool Empirica Control to solve open ended problems. No formal learning caused by the programming tool could be found. The teacher had only a questioning role. The pupils showed almost no systematic planning, reflective and creative thinking, and they often used trial and error strategies. Even when a programming tool is icon-based, it seems necessary to learn some basics before, and not during, the problem task performance. Lindh (2006) investigated the effects of Lego training on pupils’ performance on mathematics and technical tasks. The results showed an unclear picture of the contribution of Lego training in pupils’ capability solving logical problems. There was no (statistical) evidence that the average group performed better, but there was some evidence that subgroups of medium good pupils did profit of the Lego training tasks.

Hence, the assumption that the combination of constructionism, mind tools and discourse offers a great potential to promote higher-order thinking skills still asks for further research. In this study, we present some first results of a case in which Techno-Logica is used as a tool to activate intense higher-order thinking behaviour.

4 Techno-Logica as an educational tool to think with

Making teachers more sensitive to use hybrid micro worlds as a learning tool demands the breaking down of at least three barriers. First, teachers themselves should be convinced that these tools support the development of technical insights and the thinking of learners. Secondly, teachers should become more experienced and self-confident in using micro worlds fluently (Bers et al., 2002). Thirdly, the tool should easily fit in the actual educational system. Therefore, we explored the following questions:

1. Is Techno-Logica a useful mind tool to construct teacher independent and PBL?
2. Can we observe active higher-order thinking and habits of mind in such a learning environment?
3. If so, which types of higher-order thinking and habits of mind do we notice?

4.1 Techno-Logica as a concretisation tool

Techno-Logica controls an external and concrete micro world, e.g. an electromechanical toy consisting of a collection of components by a computer (e.g. construction materials such as Lego-Technic, Fisher-Technic, Lazy, K’nex with motors and sensors). Techno-Logica integrates the construction of physical models with a computer-based process controller that is made accessible through icon-oriented software and an interface. In this hybrid micro world, children can examine and experiment with physical and science concepts and their applications in technology. By using the control software, the concrete models can be programmed and controlled and a testing session gives immediate feedback. The software contains four levels of complexity: direct, automatic, interactive and collaborating mode.
4.2 The design of the children’s learning space

Based on the theoretical views of learning and thinking, our concrete experiences with these hybrid micro worlds and the research questions, we decided to design a learning space with the following six conditions:

1. The learning space exists of a concrete and a virtual world, which are interdependent and connected.
2. The problem space is limited to solving a problem in one world (virtual or real) at once.
3. A challenging problem that stimulates the learner to manipulate the objects is presented.
4. The material is teacher independent and a teacher can easily coach the pupils who use it.
5. The material is easy to learn and handle for teachers.
6. The effected learning is social-constructivistic in nature.

We used an instruction booklet, the interface Leonardo, physical objects (bulbs, motors, ground plan of a road narrowing, traffic lights and a Ferris wheel) and a computer with the software. The material is completely self-instructing. Using the booklet, a dyad successively learns three levels of the programming tool. After finishing the learning of level two (automatic mode) and three (interactive mode) the pupils get a pre-defined problem to solve. The role of the teacher is only (when necessary) to pose indirect questions. At level two, the problem to solve is designing a well-functioning programme to control the traffic lights of the road narrowing. At this level, pupils use the automatic mode to programme four output ports (bulbs) in the correct sequence. The problem of the Ferris wheel is based on some pre-described actions that should be performed. For example, ‘let the Ferris wheel turn around five times left while the bulbs flash slowly’, ‘stop the Ferris wheel for 5 sec while the bulbs flash quickly’, etc. To solve these problems, pupils have to use two output ports (bulbs and motor) and one input port (magnetic sensor). The magnetic sensor counts the number of rotations.

4.3 The implementation of the study

Our study was realised with 24 pupils of grade 8 (11 and 12 years old girls and boys) of a primary school in the Netherlands. The pupils never used Techno-Logica or a comparable product before. The teachers composed diversified dyads. The student teacher acted as a coach during the problem-solving task. He was instructed to interfere as less as possible.

By reading the explanations in the booklet and fulfilling the tasks with the concrete objects and programming software, the pupils gain enough knowledge of the functioning of the programme (Figure 3). After that, they are ready to solve a problem they have never encountered before. Manipulating this hybrid micro world is supposed to activate a thinking process that is converted in concrete programming actions that are verified by testing the concrete model. The virtual and concrete learning space makes thinking behaviour observable. The issues (the traffic lights and the Ferris wheel) are not easy to solve. For that reason, an intense verbal interaction occurs. The interaction is language-
based and aimed at solving a problem together. The interaction is goal oriented and based on the development of new knowledge (Slangen and Sloep, 2005). In this ‘progressive discourse’, (Bereiter, 1994) the various participants constantly explore ideas, provide suppositions, investigate alternatives, and search for explanations or solutions that contribute towards progress in the problem solving.

Figure 3  Dyadic reading the instruction booklet solving the problem of the K’nex Ferris wheel (see online version for colours)

4.4 The observation model

In this exploratory phase of our study, we developed two structured observation tools to proof the presence of the supposed thinking behaviour and to explore the differences in this behaviour shown during the problem solving. A second objective was to test the usability of the observation tool we developed.

We used two checklists to observe the thinking behaviour of the pupils. The first checklist is based on habits of mind as classified by Costa (2000) (Table 1). The second checklist is based on 18 thinking skills that are partly deduced from the IOWA Integrated Thinking Model (Jonassen, 2000) (Table 2). The coding scheme is build on the interpretation and classification of verbal and non-verbal utterances extracted from the discourse. Therefore, the observer could use a checklist with short descriptions of each category. For example, managing impulsivity is defined as ‘the dyad acts systematically and based on a plan is goal oriented, does not react immediately to sudden utterances or hunches without considering the consequences, strives to clarify and understand what’s happening, develops strategies to approach problems, and takes time before acting’.
Table 1  Habits of mind

<table>
<thead>
<tr>
<th>Habits of mind</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Persisting</td>
<td>9. thinking and communicating with clarity and precision</td>
</tr>
<tr>
<td>2. Managing impulsivity</td>
<td>10. gathering data through all senses</td>
</tr>
<tr>
<td>3. listening with understanding and empathy</td>
<td>11. creating, imagining, innovating</td>
</tr>
<tr>
<td>4. thinking flexibly</td>
<td>12. responding with wonderment and awe</td>
</tr>
<tr>
<td>5. thinking about thinking (meta cognition)</td>
<td>13. taking responsible risks</td>
</tr>
<tr>
<td>6. striving for accuracy</td>
<td>14. finding humour</td>
</tr>
<tr>
<td>7. questioning and posing problems</td>
<td>15. thinking interdependently</td>
</tr>
<tr>
<td>8. applying past knowledge to new situations</td>
<td>16. remaining open to continuous learning</td>
</tr>
</tbody>
</table>

Source: Costa (2000).

Table 2  Thinking skills deduced from IOWA integrated thinking model

<table>
<thead>
<tr>
<th>Thinking skills</th>
<th>Evaluating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysing</td>
<td></td>
</tr>
<tr>
<td>Recognising patterns</td>
<td>Assessing information</td>
</tr>
<tr>
<td>Classifying</td>
<td>Determining criteria</td>
</tr>
<tr>
<td>Identifying assumptions</td>
<td>Prioritising</td>
</tr>
<tr>
<td>Identifying main ideas</td>
<td>Recognising fallacies</td>
</tr>
<tr>
<td>Finding sequences</td>
<td>Verifying</td>
</tr>
<tr>
<td>Logical reasoning</td>
<td>Synthesising</td>
</tr>
<tr>
<td>Comparing and contrasting</td>
<td>Analogical thinking</td>
</tr>
<tr>
<td>Application of general rules</td>
<td>Summarising</td>
</tr>
<tr>
<td>Formulating of general rules</td>
<td>Hypothesising</td>
</tr>
<tr>
<td>Causal reasoning</td>
<td>Planning</td>
</tr>
</tbody>
</table>

The problem-solving sessions are videotaped. The recordings of progressive discourse within each dyad are analysed. Each minute the verbal and non-verbal interaction is interpreted and the four most striking habits of mind and thinking skills are scored. For seven dyads both problems (level two and three) are scored. For three dyads only the problem on level two, and for two dyads only the problem on level three is scored.

5  First results and prospective

By means of Exploratory Data Analysis this case study delivers new starting points to examine the effects of mind tools on learning more deeply. In this section, we mention our first observations, results and conclusions.

- The first question to answer is; is Techno-Logica a useful mind tool to construct teacher independent and PBL?
On the one hand, we observed that there is real PBL. The problems are challenging in a way that pupils are entirely absorbed. Most pupils stay motivated also if there seems to be no progress in solving the problem for a while. Pupils are highly engaged with the task and eager to solve the problem. The instruction booklet was completely teacher independent. On the other hand, during the problem-solving tasks we observed that coaching is regularly given. We assume a part of this coaching to be a result of the proximity of the coach. The task is not easily to solve and sometimes pupils lost motivation or reached a deadlock. Some pupils quickly ask for help and sometimes the coach is not reserved enough. We observed different kinds of coaching, e.g. short hints, open questions, motivating comments, and positive feedback. Occasionally, it is necessary for the teacher to realise a breakthrough moment in stranded thinking. Bearing in mind that learning occurs and supports participating in a social context (social constructivist learning), we prefer an interactive dialogue between pupils, and between teacher and pupils. As Slangen and Sloep (2005) emphasised, language is important to put the learners’ thoughts into words that make the thinking process explicit so that another learner or teacher can react to that process. Using this task in a regular classroom setting seems possible but needs a flexible teacher who while teaching a whole group of pupils can coach when necessary a dyad working at the task. The role of the teacher and his contribution to the problem solving should be studied in a classroom setting.

- The second question is; can we observe active higher-order thinking and habits of mind in such learning environments?

The answer to this question is surely ‘yes, we can’. Altogether we scored during 19 sessions (10 traffic light sessions and 9 Ferris wheel sessions) 8 scores every minute (4 habits of mind and 4 higher order-thinking skills) which resulted in about 9,000 scores. During the problem-solving task, we noticed an intensive progressive discourse with much active thinking behaviour and continuous reflection. We also noticed many non-verbal expressions of active thinking. By testing their programmes, pupils are directed repeatedly towards reflective thinking, they discuss solutions, verify, etc. Norman (1993) distinguishes between experiential and reflective thinking. Both kinds of thinking are assumed to be present during the problem-solving tasks. Experiential thinking becomes more precise during the self-instruction phase and increases as an effect of the learning process during the problem solving.

- Even more appealing are the answers and discussions to the third question; which types of higher-order thinking can we discern?

The observation tools in this case study are useful to examine thinking skills and habits of mind. We could discriminate between several categories of habits of mind as well as thinking skills.

The first thing, we notice are the considerable differences between the frequencies of the several categories of habits of mind (Figure 4). Most used are striving for accuracy (17%), thinking flexibly (13%), persisting (10%), questioning and posing problems (8%), listening with understanding and empathy (8%). Least used are responding with wonderment and awe (2%), taking responsible risks (2%), finding humour (2%), thinking interdependently (3%) and remaining open to continuous learning (2%). We expect these differences to be a result of the kind of mind tool we use and the type of problem-solving task.
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Figure 4  Habits of mind relative frequency scores (n = 4610) summarised over all dyads summarised for each category (see online version for colours)

For example, the hybrid micro world Techno-Logica and the tasks (traffic light and Ferris wheel) give the pupils opportunities to test their programme as often as wished. Every new test session offers clear visual feedback (the process-monitor of the software and the reactions of the concrete model) on the quality of the last changes in the control programme and on the progress in respect to the problem-solving task as a whole. This testing behaviour could be interpreted as trial and error learning. However, we regard to it as explicit actions to reach a higher level of accuracy. Since, we see pupils learning from their mistaken reasoning by gathering and interpreting feedback information during the test sessions. There are just a few scores on the category responsible risk-taking. Analysing the tasks, we have to conclude, the pupils are not confronted with real hazardous situations. On the other hand, what would the result be on the category taking responsible risks if there were a fixed amount of test sessions? Alternatively, if there was a competition component. Would there be more reasoning before testing and would there be a similar qualitative result of the problem-solving task? We expect there would explicit be more reasoning and abstract verifying before the pupils tested the concrete model. However, would using purely a virtual simulation tool (without concrete feedback) deliver same or just different scores? This example teaches us that we still have many questions to answer in respect to habits of minds, task conditions and used type of mind tool.

Secondly, we also noticed a varying intensity of the scores in some categories concerning the thinking skills (Figure 5). Predominantly, high frequencies were found in the main category of higher-order thinking skills ‘evaluating’ (44%). We found lower, nevertheless, robust higher-order thinking skills scores on connecting (22%), synthesising (18%) and analysing (16%). Therefore, we have to conclude the mind tool and task explicitly activates many of pupils’ evaluating skills. Most used evaluating skills are assessing information (13%), determining criteria (10%), verifying (10%) and recognising fallacies (7%). Least used is prioritising (3%). Our explanation for this is to
find in the properties of the task and the type of mind tool we used. Testing the programme and thinking process has much to do with the evaluating thinking skills. As we already mentioned before, the pupils have unrestricted opportunities to test the programme and model and learn from it during the problem solving session.

**Figure 5**  Thinking skills relative frequency scores \((n = 4566)\) summarised for each thinking skill category which are further classified in higher-order thinking skills (see hatching patterns) 1, Analysing 16%; 2, evaluating 44%; 3, connecting 22%; 4, synthesising 18%

Thirdly, at this point in our exploratory study, we assume there is enough active thinking behaviour to conclude that the task and mind tool are appropriate to activate higher-order thinking skills. Nevertheless, in the future it is necessary to do more research on this subject. We noticed a remarkable variety between some scores within the category synthesising. Hypothesising (8%) and analogical thinking (2%) are both outmost scores of this. We found an even bigger difference between assessing information (13%) and prioritising (3%) in the category ‘evaluating’. We assume these scores are the result of the task and the type of mind tool. Nevertheless, we still have many unanswered questions. Are scores on Habits of Mind and higher-order thinking skills somehow related? Is it possible to identify several types of mind tools and problem-solving tasks, which stimulate different sets of thinking skills?

Fourthly, the conclusion should be, the task is suitable for developing higher order thinking skills especially evaluating skills. We expect that mastering different sets of thinking skills are the important instruments for expert problem-solvers. If problem-solving and decision-making tasks do not stimulate the mastering of these skills, we should use other tasks and tools. Then the next question is: do we in this case study notice some differences between the two tasks used? The traffic light (mode 2) and Ferris wheel (mode 3) tasks are the same kind of tasks with just more complexity in the defined problem and the programme mode. Especially the interaction aspect of programme mode 3, to process input from the sensor of the Ferris wheel into right actions, is difficult for many pupils.

We observed a difference in time needed to solve the two problems. The solution of the first problem-solving task (traffic light) was for a few dyads extremely difficult. We
noticed a major time range (96 min) between the quickest dyad (24 min) and the slowest dyad (120 min). The second more complex problem-solving task showed a decrease in the time range (78 min) between the quickest dyad (46 min) and the slowest dyad (124 min). We suppose that pupils are learning to solve problems more efficient and quicker. Despite the small number of dyads, this conclusion seems also to be confirmed by a decreasing SD from 29 (traffic light problem) to 24 (Ferris wheel problem).

Observing the scores on thinking skills in case of the two problems, we did see some interesting differences and concordances (Figure 6 and 7). Comparing the dyads (seven dyads), where scored at both problem-solving tasks, we see a lot of evaluating thinking subsequently 45 and 45% for the traffic light task and the Ferris wheel task. Scores on the category synthesising show a slightly increasing pattern subsequently 16 and 18% between the traffic light task and the Ferris wheel task. However, as we look at connecting we see a substantial increasing pattern subsequently 18 and 23% for the traffic light task and the Ferris wheel task. On the contrary, analysing decreased from 21 to 14%. How is this explainable? Is the first task (traffic light) more confusing and do the pupils use different strategies and thinking skills? Have the pupils learned a more effective way of tackling the Ferris wheel problem? Do pupils have built a knowledge base and show behaviour that is more expert? We think it is plausible that learned knowledge and strategies have led to acquaintance with the computer programme, the type of task, and the relevant content of the concrete technical domain. Hence, there is less requirement and necessity for analysing actions. This also implies that the more complex Ferris wheel task does not demand for more analysing behaviour. The increasing connecting and synthesising behaviour is most likely the result of a more efficient way of using learned knowledge to solve the problem. This is in accordance with the conclusion that despite the complexity of the Ferris wheel task there was average less time needed to solve the problem. Looking separately at the dyads this trend is difficult observable (Figure 6 and 7). As we see, most dyads show the same or less analysing behaviour. However, the dispersion of the other categories differs per dyad.

**Figure 6** Dispersion of higher-order thinking skills (relative frequency) scores per dyad for traffic light problem-solving task in a cumulative column graph
The results of the case study taught us there are explicit frequency differences in the used habits of mind and thinking skills. At this point, we do not know how these differences relate to the quality of the problem-solving task. At least we expect they do. The next question could be: is there a difference between mind tools such as pure virtual simulations vs. the hybrid micro worlds? Our future aim is to study these phenomena in more depth using different tasks and types of mind tools.

6 Conclusions

We conclude by summarising the results. Our experience during the case study shows that the observation instruments are usable to score aspects of the thinking behaviour. Altogether, we found a substantial volume of active thinking behaviour. At this moment, we conclude that the problem-solving task of the kind we used forces the pupils to activate some of the habits of mind more than others. The same is to say about thinking skills. A research question that we like to pose as outcome of this case study is the following. Do different types of micro worlds and even different kinds of mind tools activate different aspects of thinking? If the answer to this question would be ‘yes’, schools should confront pupils with different kinds of mind tools. The purpose of this all is to activate different components of thinking behaviour and stimulate learning. These mind tools can vary within a class of tools such as dynamic modelling tools (micro worlds), semantic organisation tools, conversation tools and information interpretation tools. They can even vary within one class like dynamic modelling tools. Hybrid micro worlds, virtual micro worlds, simulation software, etc. could be used.

With the gathered information it is not possible to conclude anything about what Niaz (1995) described as the ‘content-process dichotomy’. The question if learning and thinking can exist without content is essential. Woodhouse (1991) formulates that it is a fallacy to suppose that generic thinking skills can exist without context. The time differences between the two problem-solving tasks points slightly at an increasing
domain specific knowledge during the tasks (more complexity less time needed). Therefore, we think it is plausible to state that the variety in using different categories of thinking behaviour (processes) is influenced by the type of content.

For this reason, it is important to carry out much more research on problem-solving tasks with dynamic modelling tools such as micro worlds or simulation software. There are several indications that these tasks stimulate more and different thinking behaviour than regular scholastic tasks. We support the presumption that thinking is learnable and a teacher can stimulate and educate it by using adequate tools and strategies. However, we should not study these skills with the intention to train them separately. The holistic view on learning teaches that human thinking is more than the sum of component skills. It is regrettable that teachers are not used to teaching with mind tools. We expect that it is possible to change this situation by means of involving student teachers.

References


