Evaluation

D E R I V E

European IST Research and Development Project

Distributed
Real and Virtual
Learning Environment
for Mechatronics and Tele-service

information society technologies

- Final Evaluation -

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Content

1 Summary

Four different learning technologies (classical components, MPS, DERIVE and virtual DERIVE) had been used to evaluate in a quasi-experimental design learning benefit, mental models and problem solving styles of the new DERIVE system. The students were taught in groups of 10, working in pairs with one learning system for 20 hour in pneumatics and electro pneumatics. In a pre-test cognitive abilities (logical reasoning, spatial abilities, technical understanding), learning styles and problem solving styles were measured. In a post-test practical abilities were measured with a practical fault finding task in a real MPS station, fault finding in a circuit diagram and a construction task. The factual knowledge was measured with a theory test, given to the students at the beginning and the end of the course. After the practical and symbolic fault finding students had to fill in a mental process questionnaire about mental models and problem solving behaviour. 16 students took part in classical components, 6 in virtual DERIVE, 19 in DERIVE and 27 in MPS station training. The average age was 18 years, SD=2.5. The classical group was significantly older. All students had less or no knowledge in pneumatics/electro pneumatics M=4 points, SD=4 (max. 79 points). Their cognitive abilities were comparable to a standardised group of vocational training students. Students described themselves as more heuristic problem solvers than algorithmic problem solvers. Learning styles did not differentiate sufficiently within and between students. However the learning benefit analysis showed a significantly differences in the increase of factual knowledge between the DERIVE group M=26, SD=5, MPS group M=25, SD=6, virtual DERIVE group M=20, SD=5 and classical components group M=19, SD=4, but 43% of the difference can be explained by technical understanding (beta=.44), and previous technical knowledge (beat=-.32) learning groups had no significant effect in the regression analysis. Also significantly differences could be found in the construction tasks between DERIVE M=31, SD=17, MPS M=23, SD=15, classical teaching M=21, SD=7 and virtual DERIVE M=14, SD=13, but still only technical understanding (beta=.37) can explain 23% test variance. In the symbolic fault finding task DERIVE M=5, SD=3 and MPS M=6, SD=3 students had been better than virtual DERIVE M=3, SD=2 and classical teaching M=1, SD=1. We identified a significant group effect (beta=.51) and technical understanding effect (beta=.31) explaining 49% of test variance. MPS students found most practical faults in the MPS station M=4, SD=1 compared to classical teaching M=3.5, SD=2, DERIVE M=3, SD=2 and virtual DERIVE M=2, SD=2, but they were faster in finding these faults. Looking at more qualitative aspects it has to be mentioned that in general students used mixed mental representations (real and symbolic) to solve the practical and symbolic fault finding. Students linked between two and three elements in their mental representation to find faults. Students with less MPS experience simulated mentally more by touching the components whereas the other students did their mental simulations just by looking at the MPS system. Many classical teaching students gave "trial and error" explanations to themselves to understand the circuit whereas DERIVE, virtual DERIVE and MPS students gave "if ...then... because" explanations. It is supposed that this is based on the fact that they have not work in advance with the MPS system. It had been difficult for all students to keep the practical task in mind and to simulate the circuit mentally but they had no problem in understanding the task. The symbolic task had been in general more difficult. In the practical and symbolic task pneumatic to electronic converter, one-flow control as well as the 5/3 solenoid valve caused most difficulties. The task difficulty averaged on a five point scale M=3, SD=1. The problem solving strategies showed clearly more "trial and error" strategies in the classical teaching group. The heuristic and algorithmic styles had similar distributions within the groups.

2 Research design

3.1 Methodological framework

The methodical framework consists of five sets of relevant variables. Learning environments are independent variables. Teaching style, teaching material and personal factors are defined as intervening variables and different kinds of learning effects are conceptualised as dependent variables (see Figure 1).

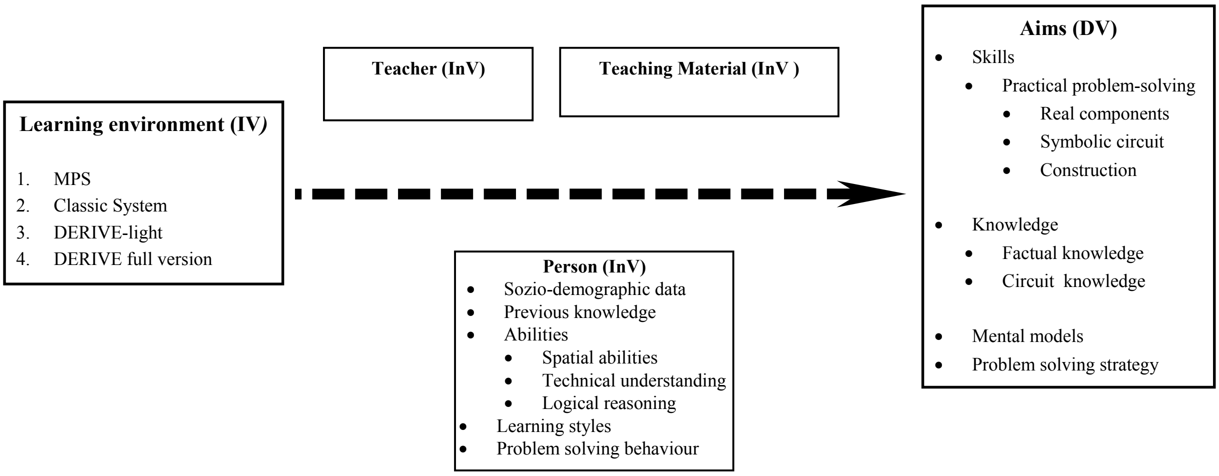

Figure 1: Methodical framework; IV: Independent variables, InV: Intervening variables, DV: Dependent variables

3.2 Research hypotheses

Research hypotheses are based on working memory (Cooper, 1998), cognitive development (Piaget, 1991) and situated learning theory (Greeno, Smith and Moore, 1993). Following hypotheses were developed in co-operation with our teacher colleagues.

1. **The possibility to switch between different representations of factual knowledge in DERIVE supports the acquisition of factual knowledge, leading to comparably more factual knowledge in the DERIVE group.**
   Baddeley (1992) and Mousavi (1995) showed that the combination of different information formats leads to a reduction of the working memory load and supports the learning process.

2. **The learning output is affected by student´s cognitive abilities, previous factual knowledge as well as by the learning environment.**
   Egan and Gomez (1985), Greene, Gomez and Devlin (1986) and Landauer (1997) showed the influence of cognitive abilities on learning output.

3. **MPS students will find more practical faults than other students.**
   These students are more familiarised in handling real components (MPS group) followed by the DERIVE full version group and the classical teaching group based on the results of situated learning effects (Greeno et al, 1993).

4. **DERIVE students have a higher mental flexibility in switching between real and symbolic representations.**
   The combination of real and virtual 3D models fosters mental ability to switch between

different representation formats.

3.3 Design

Pre-test I consisted of psychological tests given to students by a qualified psychologist three weeks before courses started. The tests were analysed at the Institute of Work Psychology. These tests were used to control intervening variables in the learning process. The test consisted of five different subtests:

- Cognitive abilities
  - Spatial ability (3DW-test)
  - Technical understanding (MTP-test)
  - Logical reasoning (PSB-test)
- Learning styles
- Problem-solving styles

Previous knowledge test in pneumatics/electro-pneumatics was delivered in pre-test 2 to be able to measure the increase in factual knowledge at the end of course. Afterwards, two courses of 10 students each started, who were taught 20 hours (60 minutes) in mechatronics at each project partner site. Students worked in pairs at one learning environment. Following learning environments were implemented and used in our teaching sessions:

1. MPS (*Modulare-Produktions-Systeme*), small production system with SPS and real components. Teaching location: FESTO Didactic
2. DERIVE-light (*virtual version*), full 3D virtual version of the small production system including SPS but no real components. Teaching location: Stockport College
3. DERIVE (*full version*), 3D virtual version link via Hyperbond with standard pneumatic components. Teaching location: TBZM-Bremen
4. MPS light (*classical teaching*), standard pneumatic components with no simulation tools. Teaching. Teaching location: ESTG-Leiria

We measured learning effects of DERIVE in a post-test, focusing on the benefit of virtual reality/real coupling via Hyperbond and learning with complex simulated systems (DERIVE-light). We delivered to students four different tests and one mental process questionnaire:

- The theory test is divided into different factual knowledge aspects (a: remember/recognition, b: circuit knowledge).
- The practical fault finding task was captured by video observation followed by a mental process questionnaire. The faults were documented by the students on a worksheet during the practical problem solving.
- The symbolic test fault finding in and a mental process questionnaire.
- The construction tasks aimed at developing a symbolic circuit wit two double acting cylinders.

The learning benefit evaluation is shown as a brief overview in Table 1.

Pre-test 1	Pre-test 2	Post-test
• **Cognitive abilities** • Logical thinking • Spatial abilities • Technical understanding • **Learning styles** • **Problem-solving styles**	• **Theory test 1**	• **Theory test 2** • **Construction task** • **2D symbolic fault finding** • Mental model questionnaire • **3D real fault finding** • Mental model questionnaire

Table 1: Evaluation design specification

The school partners agreed on following students profile:

- 17-20 years of age
- Less or no previous knowledge in pneumatics/electro-pneumatics
- In their first year of vocational or engineers training
- Voluntary participation

3.4 Instruments

3.4.1 Cognitive ability test

The standardised tests allow comparisons between the DERIVE test sample and a standardised group of similar educational levels. The cognitive test includes three sub-scales (spatial ability, logical reasoning and technical understanding).

Spatial ability

Spatial ability was measured with the 3DW (short version) (Gittler, 1989). The test task consist of the comparison between a target die and 6 rotated dice. Students have to find the right die or can also answer "No die correct" or "I don't know".

Logical reasoning

Logical reasoning was measured with the PSB (test-system for school and educational counselling, Horn, 1990). This test consists of items with manipulations of digits, letters or symbols. It includes several sub-scales that measure reasoning, word fluency, verbal comprehension, technical comprehension and numerical abilities. In the present study only sub-scales 3 and 4 were used which measure general logical reasoning ability.

Technical understanding

Technical understanding was measured with MTP (Mannheimer Test for recording physical – technical problem-solving, Conrad, Baumann & Mohr, 1980). This test aims at measuring a general ability for solving physical-technical problems and consists of 26 tasks with multiple-choice answers.

3.4.2 Learning style

The learning style questionnaire (Honey & Mumford, 1992) identifies four different kinds of learning styles. The learning style describes how people prefer to learn new subjects. The activist tackles problems by brainstorming and acting. The reflector ponders experiences from many different perspectives. The theorist adapts and integrates observations into complex and logical theories. The pragmatist tries ideas and techniques to see if they work in practice. All 80 statements must be rated by "I agree" or "I disagree".

3.4.3 Problem-solving style

The heuristic and algorithmic problem-solving questionnaire (Groner, Hess, Nussbaum & Ramirez, 1991) assumes two different problem-solving styles. These styles describe how a person is going to solve problems in general. The algorithmic problem solver tries to solve a new task based on old roles learned in the past and tasks he has in mind. The person who tries to solve each problem new without referring to old experiences is called heuristic style. All 30 statements must be rated from ”not at all” (1) to ”completely” (4) according to personal fit.

2.4.4 Theory test

The theory test covers in general pneumatics, electro-pneumatics and PLC topics (see D33). It was developed in online video conferences with school partners to carry out specific learning effect provoked by different learning environments.
The test consists of open questions, drawings and multiple choice question of increasing difficulty.
The questions cover:

- Link realistic pictures to given functions
- Link symbols to given functions
- Identify functions of different symbols
- Draw symbols
- Link pictures to symbols
- Complete different symbolic circuits (connections/numbers/elements)
- Explain the main principles in pneumatics/electro-pneumatics
- Describe operation of circuits (3 tasks increasing in difficulty)

2.4.5 Practical fault finding

The instruction for the practical test is in a textual format. Students had to put an MPS into operation by identifying five different faults. The faults are related to practical aspects as checking tube connections, adjust air, control sensors and to check air.

2.4.6 Symbolic fault finding

The students must find and correct five different faults in a 2D-circuit diagram. These fault are similar to the real faults but located at different places of the MPS circuit diagram.

2.4.7 Mental model questionnaire

The students were asked about their cognition, concepts and ideas that went through their mind during their problem-solving using a half-standardised-questionnaire (Bortz & Döring 1995). The mental process questionnaire covers categories of mental models as well as process aspects which had been found in the BREVIE study, namely:

Process descriptions:

1. Task description: starting the task, identifying faults and explanations, ending the task
2. Problem-solving strategies
3. Task complexity
4. Fault descriptions

Mental models:

1. Representation format of the mental model (3D real, 2D symbolic, text)
   The format are described that a student represents mentally in mind.
2. Amount of elements that a student linked in his explanations (one to max. four).
3. Understanding the task by thinking about previous lessons, specific components etc.
4. Mental simulation (free / fixed to components)
5. A mental simulation could be done free without any link to the present circuit or by following the tubes and components with the hands (fixed).
6. Explanation pattern (operational / functional)
   Explanation for changing tubes or components in a circuit could be: if ... then (operational) or if ... then ... because (functional) descriptions.
7. Analogies
   Analogies, e.g. water or electricity to solve the problem.
8. Difficulties (format / simulation)
   Difficulties in handling the formats (symbolic/real), in simulating the circuit mentally or with a specific component.
9. Easy aspects in the given task.
10. Required help for a similar task in the future.
11. Task severity

3 Sample

3.1 Age

Three learning groups are comparable in age (see Table 2). Classical teaching students (Portuguese students) are significant older (ANOVA) $F(3, 65)=13$, $p<.00$. A higher standard deviation could be identified in this group, because of some statistical outliners leading to the assumption that most students are of a similar age. The average age was 18 years, SD=2.5. All students were in their first year of vocational or engineer training.

Group		N	Mean	Std. Deviation
Classical teaching	Age	19	21.21	2.76
DERIVE-light	Age	6	17.83	1.17
DERIVE	Age	19	17.74	1.76
MPS	Age	25	17.76	1.76

Table 2: Age

3.2 Previous knowledge

Students had little or no previous knowledge (see Table 3) in pneumatics and electro-pneumatics.

Group		N	Mean	Std. Deviation
Classical teaching	Theoretical test in electro-pneumatics 1	19	7.47	4.11
DERIVE-light	Theoretical test in electro-pneumatics 1	7	3.86	2.61
DERIVE	Theoretical test in electro-pneumatics 1	19	1.32	2.38
MPS	Theoretical test in electro-pneumatics 1	27	3.26	4.06

Table 3: Students electro-pneumatic previous knowledge, maximum 79 points

We identified significant differences between the groups (ANOVA) $F(3, 68)=10$, $p<.00$. This difference is of no practical importance, because of the fact that students could gain a maximum of 79 points in theory test 1.

3.3 Cognitive abilities

The cognitive abilities between different learning groups showed significant differences in technical understanding (ANOVA) $F(3, 68)=2.5$, $p<.07$, spatial ability $F(3,68)=3.9$, $p<.01$ and logical reasoning $F(3, 66)=11.5$, $p<.00$ (see Table 4). This is due to the fact, that in Portugal test scores were generally lower in all aspects. The largest differences could be identified in logical reasoning. Whether these differences are of practical importance will be seen in the regression analysis of theory test 2 and the different practical tasks. Students in Portugal explained problems by solving tasks within a given time as recommend in the logical reasoning task. All test results are comparable to a standard test population in vocational training. In technical understanding and in logical thinking most of the groups are above average.
The standardised technical group gain

- in technical understanding between 9 to 14 points (40-60% of the population).
- in spatial abilities between 3-9 points (26-74% of the population).
- in logical reasoning gain up to 55 points (40% of the population) and between 65 – 68 points. (70% of the population).

Group		N	Mean	Std. Deviation
Classical teaching	Technical understanding	19	11.58	3.73
	Spatial ability	19	2.63	2.01
	Logical reasoning	19	54.79	7.88
DERIVE-light	Technical understanding	7	15.00	2.45
	Spatial ability	7	3.29	2.50
	Logical reasoning	6	67.50	5.79
DERIVE	Technical understanding	19	13.68	4.50
	Spatial ability	19	4.74	1.79
	Logical reasoning	19	64.26	5.73
MPS	Technical understanding	27	14.81	4.61
	Spatial ability	27	2.70	2.54
	Logical reasoning	26	65.04	6.37

Table 4: Students cognitive abilities, technical understanding=24 points, spatial ability=7 points, logical reasoning=80 points

The test sample is not a highly pre-selected in terms of cognitive abilities. Results can be generalised on other vocational training students.

4.4 Learning styles

The learning groups differ significantly in the two learning styles reflector (ANOVA) F (3/58)=4.98, p<.005 and theorist F (3/58)=5.15, p<003. Students can be described as reflectors. The like to stand back to ponder experiences and observe them form many different perspectives. They collect data, both first hand and from others, and prefer to think about it thoroughly before coming to any conclusion.

Group		N	Mean	Std. Deviation
Classical teaching	Activist	19	9.47	2.72
	Reflector	19	16.68	2.81
	Theorist	19	12.68	2.56
	Pragmatist	19	12.37	2.39
DERIVE-light	Activist	5	10.80	3.83
	Reflector	5	13.20	3.42
	Theorist	5	11.00	1.73
	Pragmatist	5	11.60	2.88
DERIVE	Activist	16	9.88	3.12
	Reflector	17	12.88	3.62
	Theorist	17	8.59	4.49
	Pragmatist	17	11.59	3.48
MPS	Activist	15	10.27	2.89
	Reflector	18	14.22	3.14
	Theorist	16	10.75	2.08
	Pragmatist	17	12.06	2.08

Table 5: Learning styles, maximum 20 points in each category

The activist is less often described than in the BREVIE test sample. In general differences between these learning styles are to small to identify a typical problem solving style within these groups. Thus, learning styles will not be implemented in further detailed group analyses. On the final DERIVE meeting these results had been discussed with our school partners. In their opinion this is an instrument that is widely used but produces invalid results.

3.4 Problem solving style

The problem solving style questionnaire shows that students characterise themselves as heuristic problem solver (see Table 6). We found significant differences between the learning groups (ANOVA) F (3/68)=5.25, p<.003. Classical teaching students describe themselves as less heuristic than the other students.

Group		N	Mean	Std. Deviation
Classical teaching	Algorithmic problem solver	19	30.16	4.67
	Heuristic problem solver	19	43.53	4.74
DERIVE-light	Algorithmic problem solver	7	34.29	16.30
	Heuristic problem solver	7	54.57	11.98
DERIVE	Algorithmic problem solver	19	28.16	5.03
	Heuristic problem solver	19	46.84	5.16
MPS	Algorithmic problem solver	27	29.26	4.64
	Heuristic problem solver	27	46.63	6.06

Table 6. Problem solving styles, maximum 60 points in each category

The heuristic problem solving behaviour is based on looking at task description, analysing a circuit and developing a problem-solving strategy. The algorithmic problem solver uses predefined procedures learned in the past to solve a problem.

4 Results

4.1 Theory test

The theory test measures general electro-pneumatic factual knowledge. The test is divided into two aspects (1) factual knowledge (remember and recognise) and (2) circuit knowledge (mental simulation is required to find a solution).
The present results are gained by differences between theory test one and theory test two describing the increase of knowledge. We found significant differences between the learning groups (ANOVA) $F(3, 68)=7.6$, $p<.00$.

Group		N	Mean	Std. Deviation
Classical teaching	Factual knowledge	19	19	4
	Circuit knowledge	19	17	5
DERIVE-light	Factual knowledge	7	20	5
	Circuit knowledge	7	12	4
DERIVE	Factual knowledge	19	26	5
	Circuit knowledge	19	19	6
MPS	Factual knowledge	27	25	6
	Circuit knowledge	27	19	6

Table 8: Increase of factual (maximum 43 points) and circuit knowledge (maximum 36 points)

Hypothesis one is verified on this analytic step, but detailed regression analysis show that factual knowledge differences are not effected by the learning environment but by technical understanding and previous knowledge (see Table 9).

R	R Square	Adjusted R Square	Std. Error of the Estimate
.66	.43	.39	4.60

	Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	13.81	4.56		3.03	.00
Group	.87	.57	.18	1.51	.14
Previous theoretical knowledge	-.44	.15	-.32	-2.99	.00
Technical understanding	.59	.15	.44	4.10	.00
Spatial ability	-1.336E-02	.25	-.01	-.05	.96
Logical reasoning	1.678E-02	.08	.02	.20	.84

Table 9: Regression analysis of factual knowledge

The learning environment (group) has no significant effect. Factual knowledge variation can be explained (43%) with technical understanding and previous electro pneumatic knowledge.

Parts of circuit knowledge can also be explained r=.28 with technical understanding as a personal ability.

R	R Square	Adjusted R Square	Std. Error of the Estimate
.52	.28	.22	5.40

	Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	10.06	5.36		1.88	.07
Group	.30	.67	.06	.44	.66
Previous theoretical knowledge	.12	.17	.08	.66	.51
Technical understanding	.66	.17	.47	3.89	.00
Spatial ability	.40	.30	.15	1.36	.18
Logical reasoning	-6.048E-02	.10	-.08	-.62	.54

Table 11: Regression analysis of circuit knowledge

Major groups differences are identified in logical reasoning but they had no effect on the increase of electro pneumatics knowledge.

4.2 Construction task

We identified significant differences between the learning groups (ANOVA) F (3/68)=3.10, p<.04 in the construction task. All students needed similar time to construct the circuit.

Group		N	Mean	Std. Deviation
Classical teaching	Construction task	19	21.21	7.54
	Construction task solving time	19	46.26	10.85
DERIVE-light	Construction task	7	13.86	12.92
	Construction task solving time	7	27.29	6.34
DERIVE	Construction task	19	30.89	16.58
	Construction task solving time	19	42.11	9.79
MPS	Construction task	27	23.11	15.28
	Construction task solving time	27	43.85	12.52

Table 13: Construction task performance, maximum 46 points

The short problem solving time in DERIVE-light is due to the fact that these students had been less motivated during the final test as observed by the evaluator. It was difficult to keep these students on track to perform the final evaluations. Again 23% of the test variance are explained by technical understanding (beta=.37). All other factors had no significant influence. It has to be mentioned that only three of the students received 46 points, all belonging to the DERIVE group.

4.3 Symbolic task

We identified a significant difference between the learning group in the symbolic fault finding task (ANOVA) F (3/68)=14.81, p<.00. We found a significant group effect (beta=.51) and technical understanding (beta=.31) explaining 49% test variance.

Group		N	Mean	Std. Deviation
Classical teaching	Symbolic task	19	1.05	1.35
	Symbolic task solving time	19	17.89	4.79
DERIVE-light	Symbolic task	7	3.14	2.48
	Symbolic task solving time	7	20.43	6.55
DERIVE	Symbolic task	19	5.00	3.18
	Symbolic task solving time	19	22.58	6.27
MPS	Symbolic task	27	6.07	2.85
	Symbolic task solving time	27	22.26	6.81

Table 13: Symbolic task performance, maximum 10 points

The problem solving time is comparable between the groups. The classical teaching group was a little bit faster but not significantly. 5 MPS and 3 DERIVE students could realise a fully functioning circuit. Fewer solutions were found compared to the practical task, where 15 MPS, 8 DERIVE, 1 DERIVE-light and 8 classical teaching students found a fully functioning solution.

4.4 Practical task

The practical task as instrument to measure practical competence shows significant differences

Group		N	Mean	Std. Deviation
Classical teaching	Practical task	18	3.50	1.65
DERIVE-light	Practical task	7	1.71	1.70
DERIVE	Practical task	19	3.00	1.67
MPS	Practical task	27	4.22	1.05

Table 14: Practical performance, maimum 5 points

between the groups (ANOVA) F (3/68)=6.43, p<001. Students with more hands-on experience found more faults as other students. Hypothesis three has been verified. The problem solving time has wide in-between variance. Cognitive abilities are less important for practical problem solving compared to factual knowledge for good task performance. Only 16% variance could be explained with technical understanding (beta=.36). All other variables had no significant effect.
The test time for students who build up a fully functioning circuit did not differ between the groups (see Table 15). The learning environment had no effect on the efficiency but on the effectiveness of the problem solving behaviour for these groups.

Group		N	Mean	Std. Deviation
Classical teaching	Practical test solving time	8	34.38	13.38
DERIVE-light	Practical test solving time	1	20.00	.
DERIVE	Practical test solving time	6	34.17	10.59
MPS	Practical test solving time	15	34.87	14.98

Table 15: Practical performance time, maximum 60 minutes time

4.5 Mental models

The next chapter presents results of our mental process questionnaire describing qualitative differences in knowledge representation, explanation formats etc which had been mentioned in chapter (3.1.7).

4.5.1 Mental model format

Students represent practical and symbolic tasks mainly as real representation (see table 15 & 16). DERIVE did not support students in developing a higher mental representation flexibility. They also stick to a real representation. Many students worked with mixed representations in the symbolic task.

			Real Representation	Symbolic Representation	Mixed Representation	Textual Representation
Group	Classical teaching	Sum	11	1	7	0
	DERIVE-light	Sum	5	0	2	1
	DERIVE	Sum	14	1	2	1
	MPS	Sum	15	4	9	1

Table 15: Practical task: representation format

			Real Representation	Symbolic Representation	Mixed Representation	Textual Representation
Group	Classical teaching	Sum	12	3	4	0
	DERIVE-light	Sum	5	0	2	1
	DERIVE	Sum	6	4	6	5
	MPS	Sum	11	3	14	1

Table 16: Symbolic task: representation format

4.5.2 Mental elements

Student linked mentally two to three elements in the practical task in order to solve the fault finding task. In the symbolic fault finding task students mainly linked two elements. This seems to be clear because a mental simulation is required to identify a fault which is much easier with two than three components. In the partical problem solving task the simulation can be done externally by pushing a bottom.

			One Mental Element	Two Mental Elements	Three Mental Elements	Four Mental Elements
Group	Classical teaching	Sum	4	6	4	6
	DERIVE-light	Sum	0	5	3	0
	DERIVE	Sum	2	8	7	3
	MPS	Sum	2	15	12	1

Table 17: Mental elements in the practical task

			One Mental Element	Two Mental Elements	Three Mental Elements	Four Mental Elements
Group	Classical teaching	Sum	5	8	6	4
	DERIVE-light	Sum	2	3	2	0
	DERIVE	Sum	2	9	6	2
	MPS	Sum	3	17	6	1

Table 18: Mental elements in the symbolic task

4.5.3 Simulation

There are different kinds of doing a mental simulation. The students could answer between "never" = 0 to "always" = 6. They were asked, how they simulate the different tasks mentally:

- ... by reading the given task.
- ... by looking at the real MPS.
- ... by following the MPS with my hands.
- ... by touching the MPS.
- ... just in my mind, without any contact to the task.

Practical task simulation by

Group		N	Mean	Std. Deviation
Classical teaching	Reading	18	4.44	1.54
	Looking	18	4.61	1.14
	Following	18	4.11	1.41
	Touching	18	4.67	1.14
	Thinking	18	2.00	.91
DERIVE-light	Reading	7	3.57	1.81
	Looking	7	3.57	1.90
	Following	7	4.29	1.70
	Touching	7	4.43	1.27
	Thinking	7	2.43	1.62
DERIVE	Reading	18	2.28	1.67
	Looking	19	4.42	1.43
	Following	18	2.72	1.64
	Touching	19	3.47	2.06
	Thinking	18	2.33	1.71
MPS	Reading	27	3.22	1.53
	Looking	27	4.52	1.28
	Following	27	2.93	1.77
	Touching	27	3.11	1.67
	Thinking	27	2.52	1.72

Table 19: Simulation of the practical task, 1="never" and 6="always"

Student who were less familiarised with the MPS system (real or virtual) simulated their mental model by touching the real components, whereas the other students simulated more by looking at the circuit, without touching it.

Symbolic task simulation by

Group		N	Mean	Std. Deviation
Classical teaching	Reading	18	4.83	1.04
	Looking	18	3.67	1.24
	Following	18	3.44	1.65
	Touching	18	2.06	1.30
	Thinking	18	2.44	1.20
DERIVE-light	Reading	7	3.43	1.51
	Looking	7	3.43	1.40
	Following	7	3.57	1.27
	Touching	7	2.00	1.15
	Thinking	7	4.57	1.13
DERIVE	Reading	19	3.11	1.73
	Looking	18	4.11	1.23
	Following	19	3.53	1.71
	Touching	19	3.21	1.72
	Thinking	19	1.89	1.37
MPS	Reading	27	3.89	1.42
	Looking	27	4.19	1.14
	Following	27	3.11	1.53
	Touching	26	3.31	1.69
	Thinking	27	2.67	1.57

Table 20: Symbolic task simulation by, 1="never" and 6="always"

Classical teaching students simulated the task mainly by reading and looking at the circuit diagram. DERIVE-light students simulated the circuit just by thinking. DERIVE students simulated the circuit by looking at the task and by following the symbols with their hands. MPS students simulated the circuit by reading the task and looking at the diagram.

4.5.4 Explanation types

Students were asked how they explained circuit functions to themselves. They could give multiple answers on the sheet.
In tendency classical students used "if...then...because" explanations or "trial and error" explanations, thus they changed components by testing the system without knowing what could happen next. This "trial and error" behaviour is less used in the other groups. Especially the MPS group gave "if...then" or "if...then... because" explanations in both tasks.

			Explanation Type "if ... then"	Explanation Type "if ... then ... because"	Explanation Type "Trial and Error"	Explanation Type "other"
Group	Classical teaching	Sum	4	12	11	0
	DERIVE-light	Sum	4	2	3	0
	DERIVE	Sum	7	11	4	0
	MPS	Sum	14	13	4	1

Table 21: Practical explanation types

			Explanation Type "if ... then"	Explanation Type "if ... then ... because"	Explanation Type "Trial and Error"	Explanation Type "other"
Group	Classical teaching	Sum	8	12	4	0
	DERIVE-light	Sum	3	3	1	1
	DERIVE	Sum	7	12	0	1
	MPS	Sum	15	13	2	1

Table 22: Symbolic explanation types

4.5.5 Problems with the task

Students were asked which task aspect had been difficult during the problem solving process. In general it had been difficult for all groups to keep the task (circuit functions and way step diagram) in mind. Everybody understood the task. DERIVE students rated the task as very easy. Finally, all students found it quite difficult to simulate the circuit mentally.

Difficulties to ...

Group		N	Mean	Std. Deviation
Classical teaching	Understand the task	18	2.33	.97
	Develop sub-tasks	18	2.89	1.18
	Handle real components	18	2.83	1.34
	Simulate circuit mentally	18	2.78	1.11
	Keep circuit in mind	18	3.11	1.23
	others	1	2.00	.
DERIVE-light	Understand the task	7	2.43	.53
	Develop sub-tasks	7	2.57	.98
	Handle real components	7	3.00	1.91
	Simulate circuit mentally	7	3.00	1.53
	Keep circuit in mind	7	3.14	1.86
	others	1	2.00	.
DERIVE	Understand the task	19	1.53	.61
	Develop sub-tasks	19	2.32	1.25
	Handle real components	19	2.63	1.42
	Simulate circuit mentally	19	2.74	1.37
	Keep circuit in mind	19	3.05	1.13
	others	3	2.67	.58
MPS	Understand the task	27	2.15	.82
	Develop sub-tasks	27	2.22	.80
	Handle real components	27	2.63	1.15
	Simulate circuit mentally	26	2.92	1.23
	Keep circuit in mind	27	3.30	1.17
	others	5	3.80	1.48

Table 23: Problem with the task, 1=”very easy” and 6=”very difficult”

The symbolic task had been more difficult in nearly all aspects. The classical teaching group and DERIVE-light had major difficulties in understanding the task and in simulating him mentally. For the MPS students it also had been difficult to understand the task and to keep it in mind. The DERIVE group had problems in mental simulation and to keep the circuit in mind.

Difficulties to ...

Group		N	Mean	Std. Deviation
Classical teaching	Understand the task	18	3.61	1.24
	Develop sub-tasks	18	3.00	1.19
	Simulate circuit mentally	18	3.44	1.20
	Keep circuit in mind	18	3.50	1.15
	others	2	2.50	.71
DERIVE-light	Understand the task	7	4.00	1.00
	Develop sub-tasks	7	2.43	.98
	Simulate circuit mentally	7	2.43	1.62
	Keep circuit in mind	7	3.57	1.72
	others	1	3.00	.
DERIVE	Understand the task	19	2.21	.98
	Develop sub-tasks	19	2.21	1.08
	Simulate circuit mentally	19	2.95	1.31
	Keep circuit in mind	19	3.11	1.29
	others	4	3.25	1.26
MPS	Understand the task	27	3.07	1.07
	Develop sub-tasks	27	2.63	.93
	Simulate circuit mentally	27	2.96	1.29
	Keep circuit in mind	27	3.44	.85
	others	6	3.17	1.33

Table 24: Difficulties to work with the simulated circuit, 1="very easy" and 6="very difficult"

4.5.6 Component difficulty

We asked students to score the degree of difficulty caused by each component during their problem solving. They could answer between “very easy” (1) to “very difficult” (6). The major results are presented here, some components seem to be very easy to understand and some cause difficulties. Symbols had been a little bit more difficult than real components. For all students pneumatic to electronic converter and one-flow control valve as well as 5/3 solenoid valve had been difficult, independently how the students approached or analysed these components.

	Practical task	Symbolic task
Classical teaching	Range: M=1.39 to 3.39	Range: M=1.33 to 4.11
	Pneumatic to electronic converter M=3.39	One-flow control valve M=4.11
	One-flow control valve M=3.28	Differential pressure switch M=3.56
	5/3-way solenoid valve, mid position closed M=3.24	Semi-rotary actuator M=3.33
DERIVE-light	Range: M=1.14 to 3.86	Range: M=1.00 to 4.83
	One-flow control valve 3.86	Pneumatic to electric converter M=4.83
	Pneumatic to electronic converter M=3.86	Differential pressure switch M=4.57
	5/3-way solenoid valve, mid position closed M=3.43	One-flow control valve M=3.83
DERIVE	Range: M=1.11 to 3.58	Range: M=1.11 to 3.95
	Make switch M=3.58	Make switch M=3.95
	5/3-way solenoid valve, mid position closed M=3.56	Pneumatic to electronic converter M=3.63
	Pneumatic to electronic converter M=3.26	5/2-way solenoid impulse valve M=3.44
MPS	Range: M=1.41 to 3.96	Range:M=1.22 to 3.85
	5/2-way solenoid impulse valve M=3.96	5/2-way solenoid impulse valve M=3.85
	Make switch M=3.96	Make switch M=3.85
	Pneumatic to electronic converter M=3.78	Pneumatic to electronic converter M=3.59

Table 24: Difficulties with components, 1=”very easy” and 6=”very difficult”

4.5.7 Task difficulty

The general task severity judgement shows no differences within and between the group, expect for the DERIVE-light group judging both tasks as easier compared to other students.

Group		N	Mean	Std. Deviation
Classical teaching	Task Severity Practical Task	18	3.11	.83
	Task Severity Symbolic Task	18	2.72	.83
	Valid N (listwise)	17		
DERIVE-light	Task Severity Practical Task	7	2.00	.82
	Task Severity Symbolic Task	7	2.43	.98
	Valid N (listwise)	7		
DERIVE	Task Severity Practical Task	19	2.95	.97
	Task Severity Symbolic Task	19	3.11	.74
	Valid N (listwise)	19		
MPS	Task Severity Practical Task	27	3.00	.92
	Task Severity Symbolic Task	27	3.07	.68
	Valid N (listwise)	27		

Table 25: Task Severity for practical and symbolic fault finding, 1=”very easy” and 5=”very difficult”

5.6 Problem solving behaviour

The three open questions dealing with task approach, problem solving strategies and handling the task complexity where given to the students. Students had difficulties to be answer these questions seperatly. Also, they had limited writing skills leading to sometimes unreadable and unintelligible statements. We decided for qualitative analysis to link all aspects together to gain problem solving strategies (60 page text document). We followed Mayrings (1993) concept of analysing text data:

1. Data transcription
2. Paraphrasing
3. Generalisation
4. Extraction of problem solving styles

We could differentiate between three problem solving styles.

1. The heuristic type is characterised by starting to get a task overview at the beginning, then to understand the task in detail and getting an status understanding of the circuit in front of him and afterwards he is starting to develop a task adequate fault finding strategy.

2. The algorithmic type is characterised by solving tasks step by step, for example starting from

the bush button to the end of the circuit or the solved the electric part followed by pneumatic part or vice versa or checked systematically inputs and outputs. The major difference compared to the heuristic type is his predefined problem solving behaviour independently of the specific task situation. This person has a clear procedure how to solve pneumatic problems in general.

3. The trial and error type is characterised by lack of a systematic approach. He scans around a task and checking parts without knowing what should happen exactly. They described their behaviour as jumping from one part to another.

	Heuristic type	**Algorithmic type**	**Trial and error**
Classical teaching	5 (28 %)	4 (22 %)	9 (50 %)
DERIVE-light	5 (71 %)	0 (0 %)	2 (19 %)
DERIVE	5 (26 %)	7 (37 %)	7 (37 %)
MPS	11 (41 %)	11 (41 %)	5 (18 %)

Table 26: Problem solving styles

50 % of the classical teaching group used "trial and error" strategies to solve the practical fault finding task followed by DERIVE students with 37%. Since the classical teaching group had no experience with the real MPS a "trial and error" strategy is reasonable. Within the groups there are only small differences between heuristic and algorithmic problem solving behaviour.

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6 Appendix

6.1 Mental Process Questionnaire

Evaluation **D E R I V E** **European IST Research and Development Project**

Distributed
Real and Virtual
Learning Environment
for Mechatronics and Tele-service

Mental Process Questionnaire

This questionnaire aim at a description of your **mental processes**. This can be done, if you try to go back into ***putting an MPS into operation*** or ***symbolic fault finding*** and try to remember as much of your thoughts as you can. The task, pictures of the MPS and your worksheet shell help you to remember as many details as possible. Take your time to answer the questions **precisely** and **complete**. It is of major importance for further developments that we receive honest answers. It is better to think twice about what you **thought** than to write down a coherence process which does not reflect your thoughts of the situation. It does not matter how you thought, e.g. structured or unstructured, if you had problems with components, etc. **that is fine**! We are interested in what really went through your mind during the task?

Task approach

How did you **approach** the task?
Please, describe the steps that you went through during the problem-solving task: starting from the beginning to the end of the task, e.g. read the task, visualise the task, anticipate difficult aspect, experimented with the circuit to understand ...
Further questions shell help you to think more about your **processes** and **steps**:

- What were your aims at the beginning?
- What did your have in mind while working with the circuit?
- Which thoughts, ideas, presumptions or sentences went through your head/mind?

Fault Description

Which faults did you find and **why** do you think these were the faults? You can use your worksheet to remember the ideas and explanations you had during the task preparation!

Fault (Which?)	What happened with the circuit? (Why?)
1.	
2.	
3.	
4.	
5.	

6.	
7.	

Personal strategy

Did you have a personal **strategy** to solve this task? Please describe the steps and elements of you procedures, e.g. 1. reading task, 2. change a component, 3. test, 4. change, test, ...

Task complexity

How did you handle the **task complexity**, e.g. try to find all faults at once, divided the task into subtasks, worked at the switches first, worked at the cylinders first, and then ....
Please give us a detailed description of your way to reduce the task complexity.

Mental models

People build models mentally to solve different tasks. We now like to know, if you developed your own mental model about the MPS and how did it look like?

1. Did you develop any kind of model in our mind to solve the task? Mark your answer with a cross.

MM1	Yes	♣
	No	♣

2. If not, how did you solve the problem in your mind by thinking ... how?

3. How did you represent the circuit in your mind? Mark your answers with a cross.

	Formats		**Which components?**
MR1	as real components (picture)	♣	
MR2	as symbols (picture)	♣	
MR3	mixture of both	♣	
MR4	textual	♣	

4. Did you simulate the MPS mentally? Mark your answer with a cross.

	Yes	No	Which parts of the MPS?
MS1	♣	♣	

5. How did you simulate the MPS mentally? Score the personal fit of each statement with a cross.

	Statements	Judgement never → always
MT1	... by reading the given task.	1 2 3 4 5 6
MT2	... by looking at the real / symbolic MPS.	1 2 3 4 5 6
MT3	... by following the MPS / symbolic circuit with my hands.	1 2 3 4 5 6
MT4	... by touching the MPS.	1 2 3 4 5 6
MT5	... just in my mind, without any contact to the task.	1 2 3 4 5 6

6. How many elements did you link in your mental simulations? Mark it with a cross.

	Elements		Which elements did you link mentally?
ME1	1	♣	
ME2	2	♣	
ME3	3	♣	
ME4	4	♣	

7. How did you try to understand the functions of the circuit? Mark your answers with a cross.

	Statements		**Which aspects?**
MU1	... remembered a task from previous lessons.	♣	
MU2	... remembered components from previous lessons.	♣	
MU3	... did system tests with the circuit and compared it with my personal view of it's behaviour.	♣	
MU4	... remembered similar tasks from my workplace.	♣	
MU5	... used my practical experience with technical systems.	♣	
MU5	other ...	♣	

8. How did you explain circuit functions to yourself?
Probably you gave yourself, e.g. if cylinder 1A moves out then cylinder 1 A moves in or just trial and error to find a solution. Mark your answers with a cross.

	Explanation Type	
MM1	if ... then ...	♣
MM2	if ... then ... because	♣
MM3	trail and error	♣
MM4	other ...	♣

9. Did you use analogies to understand the circuit and which?
Did you think about the behaviour of water, electricity or something else to solve the problem?

10. Score each statement according to the problems they caused to you by putting a cross in each row.

	Statements	Judgement very easy → very difficult
MP1	Understanding the written task.	1 2 3 4 5 6
MP2	To split the task into sub steps.	1 2 3 4 5 6
MP3	Handling the real components.	1 2 3 4 5 6
MP4	Handling the symbolic circuit.	1 2 3 4 5 6
MP5	Simulate the circuit mentally.	1 2 3 4 5 6
MP6	Keep different elements at once in my mind.	1 2 3 4 5 6
MP7	other ...	1 2 3 4 5 6

11. Score each component according to the problems they caused to you by putting a cross in each row.

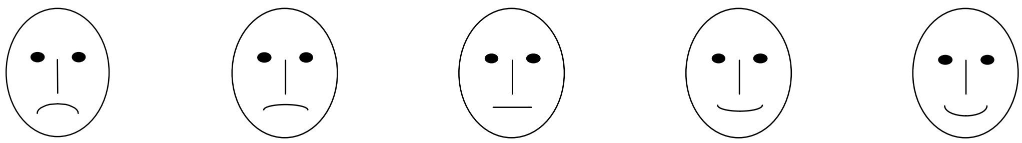
	Components	**Judgement** **very easy → very difficult**
CD1	Double acting cylinder	1 2 3 4 5 6
CD2	5/2-way solenoid valve	1 2 3 4 5 6
CD3	One-way flow control valve	1 2 3 4 5 6
CD4	5/3-way solenoid valve, mid-position closed	1 2 3 4 5 6
CD5	Semi-rotary actuator	1 2 3 4 5 6
CD6	One-way flow control valve	1 2 3 4 5 6
CD7	Vacuum suction nozzle	1 2 3 4 5 6
CD8	Sucker	1 2 3 4 5 6
CD9	5/2-way solenoid impulse valve	1 2 3 4 5 6
CD10	Differential pressure switch	1 2 3 4 5 6
CD11	Pushbutton (make)	1 2 3 4 5 6
CD12	Magnetic proximity switch	1 2 3 4 5 6
CD13	Make switch	1 2 3 4 5 6
CD14	Pneumatic to electric converter	1 2 3 4 5 6
CD15	Optical proximity switch	1 2 3 4 5 6
CD16	PLC DDE Input Port	1 2 3 4 5 6
CD17	PLC DDE Output Port	1 2 3 4 5 6
CD18	Valve solenoid	1 2 3 4 5 6
CD19	Electrical connection 24V	1 2 3 4 5 6
CD20	Electrical connection 0V	1 2 3 4 5 6
CD21	Compressed air supply	1 2 3 4 5 6

12. What was easy for you?

13. What kind of help would you like to get in the future for a similar task?

Task severity

How would you score the severity of the task in general? Mark your answer with a cross.



1	2	3	4	5
very difficult	difficult	average	simple	very simple