Visual Problem Solving and Self-regulation in Training Air Traffic Control

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CHAPTER 1

General Introduction

Suppose you are selected for the training in air traffic control (ATC) and you enroll in ATC training, a course of study that takes at least two years. After completing the training, you are expected to perform your job as air traffic controller perfectly; life must never be at risk. While safety is first, efficiency in terms of aircraft flight time and fuel consumption is also important in ATC. Working on the fine line between safety and efficiency makes ATC very complex and makes the work of an air traffic controller a sustained effort to find optimal solutions. The decisions that an air traffic controller makes are primarily based on visual input (e.g., from the radar screen) in interaction with radio telephony with the pilots in the cockpits. The real art in such a complex visual-based task is to quickly determine and interpret relevant information so as to guarantee a safe but quick decision making process (Jarodzka, Van Gog, Dorr, Scheiter, & Gerjets, 2013; Oprins & Schuver, 2003). Training this decision making process, however, is a challenging task for at least three reasons.

First, the decision making process is difficult to observe. Hence, it is difficult for students to use each others' performances as examples (i.e., those of an expert air traffic controllers or more advanced colleague students) and for coaches to assess precisely where students encounter problems and what those problems are since the decision making process is interwoven in a number of other domain specific competences (i.e., it involves situational assessment; Oprins & Schuver, 2003).

The second reason that it is so challenging is that the assessment of decision making can be difficult because: The complexity of the domain makes it likely that there are multiple arguable solutions for a single air traffic situation while the underlying strategies could be similar. But different strategies can lead to similar solution depending on expertise level (Fields, 2006; Medin, et al., 2006). Thus, insight should be provided into these underlying strategies and how they relate to expertise development.

The third reason is that students must not only master the situation as it is at the moment of their training, but they must also be prepared for changes in working procedures and conditions due to technological innovations, changes in the rules governing air traffic and its control, and due to an increasing rate of traffic (Eurocontrol Statfor, 2010). Training, thus, must focus on the development of complex domain-specific competences and also prepare the students for continuous learning throughout their career so that they can deal with future changes.

This dissertation has as main research question: How can ATC training focus on successfully teaching complex ATC skills while at the same time preparing the future air traffic controller for working in a dynamic environment which demands continuous learning? Therefore, on the one hand, the dissertation elaborates on the training of ATC specific competences, particularly those related to *visual expertise*. On the other hand, it focuses on *regulation skills* for successful training in ATC and the possibilities to embed the development of regulation skills in training.

Expertise in Air Traffic Control

ATC is primarily a perceptual task (Chi, 2006) where task performance heavily relies on visual search and visual information interpretation (i.e., perception, attention management, interpretation; Oprins & Schuver, 2003). In radar control, a continuous flow of small plots representing aircraft must be kept separated from each other (i.e., with a minimum of 5 nautical mile (9,3 km) horizontal and/or 1000 foot (300 m) vertical separation) and must be guided in an efficient way (i.e., short route, continuous speed, continuous climb/descent) to their individual destination points. Each plot is completed with a label comprising important flight information (i.e., current flight level, heading, and speed; requested flight level, speed, and route). All this information is crucial for guaranteeing safe and efficient ATC. While it has widely been shown that experts are capable of using visual strategies that allow for fast and correct selection of required screen information (cf. Gegenfurtner, Siewiorek, Lehtinen, & Säljö, in press), research focused on training visual problem-solving has been limited (Gegenfurtner, Lehtinen, & Säljö, 2011; Jarodzka, Boshuizen, & Kirschner, 2012). If it is the case that experts use strategies that differ from intermediates and novices (Boshuizen & Schmidt, 2008), then it is important to take this into account for designing training for complex perceptual skills (e.g., examining CT or ultrasound scans, controlling dynamic chemical processes, ATC). Therefore it is important to determine which visual strategies are used in visual problem-solving at different levels of expertise. While there is a fair amount of research on expert-novice differences, the number of studies that include intermediates is limited

(Gegenfurtner et al., 2011). Therefore the first study in this dissertation focuses on what these strategies are in ATC, which strategies are used at which level of expertise, and whether these strategies lead to similar solutions. Results from research described in this dissertation can give important input for training visual problem-solving by means of eye-movement modeling examples. Recent research by Jarodzka et al. (2013) studied the use of eye-movement modeling examples for instructional purposes and showed that it was possible to train problem-solving skills in perceptual tasks by showing learners - who were required to learn identify and classify complex movement patterns in the domain of biology - the eye-movements of experts in that domain. To design eye-movement modeling examples in a domain, visual strategies per level must be mapped out. Hence, this study gives input for adapting eye-movement models behavior to students' learning needs in ATC.

Students' Regulation Skills

The domain of ATC is not only visually complex, but it is also constantly evolving at what seems to be an increasing rate (Eurocontrol Statfor, 2010). Air traffic controllers are regularly confronted with major changes in the technologies that they are required to use in order to keep up with ever increasing air traffic. Also, the work procedures and regulations they must follow change regularly due to national and international agreements, for example, on noise and air pollution. Therefore, air traffic controllers and ATC-students not only need to master domain specific ATC competencies (Oprins, Burggraaff, & Van Weerdenburg, 2006), but they also need to be able to react adequately to changes in their work, maintain their expertise and remain competent across their working lifetime (Ericsson, Krampe, & Tesch-Romer, 1993), continuously learn and relearn (Norman, 1988), and direct their own learning for optimal results (Eva & Regehr, 2005). Therefore, they must also develop regulation skills to keep up with their unremittingly changing working environment (Boekaerts & Cascallar, 2006; Bolhuis, 2003; Candy, 1991; Van Merriënboer, Kirschner, Paas, Sloep, & Caniëls, 2009). While specific training of the necessary regulation skills is recommended for improving learning (Salden, Paas, & Van Merriënboer, 2006; Zimmerman, 2002), their inclusion in training programs is not often the case.

Before beginning on the design of an ATC learning environment which also will foster the acquisition of self-regulation skills, the question of which regulation skills are of major importance in ATC has to be answered by all stakeholders in the training. This is so important because self-regulation, in itself, is a complex concept. Self-regulation skills can be divided in self-regulated learning (SRL) skills, self-directed learning (SDL) skills and self-efficacy. This classification allows to distinguish between three levels of self-regulation (Brand-Gruwel et al., 2013; Loyens, Magda, & Rikers, 2008; Chapter 3; 4). The first level refers to students' SRL skills and enables students to regulate task performance. The use of these skills allows the student to think of her/his own learning opportunities offered by a learning task (e.g., How did I do on the task? What information do I need to properly carry out the task?). The second refers to students' SDL skills and enables students to regulate over different tasks. The use of these skills allows students to direct own learning activities (e.g., selecting learning tasks) and to choose coaching that is needed at that very moment in training. (e.g., seeing as how I did on the task, which task should I choose next?). The third level refers to students' self-efficacy and includes the students belief about performing well (e.g., I feel that I am capable of carrying out the task) and fosters the effort put in learning. For successful learning it is important that all stakeholders in ATC training (i.e., trainees, trainers/coaches, designers) understand the requirements and design of a successful learning environment; have the same cognitions about the environment (Elen & Lowyck, 1998, 1999; Könings, Brand-Gruwel, & Van Merriënboer, 2005). Once these cognitions are known, a design can be made, implemented and tested.

This dissertation deals with both visual expertise and the development of students' regulation skills in a visually complex – ATC - domain. To further improve training in that domain, this dissertation attempts to answer the following research questions:

1. What visual strategies do experts, intermediates, and novices use in the field of ATC?
2. Which regulation skills are important for ATC students according to the different stakeholders in the training process?

3. What are the requirements for a learning environment that is intended to integrate the development of domain-specific and self-regulation skills in a cognitively complex domain such as ATC?
4. What is the effect of an integrated training of self-regulation skills on students' self-regulation and domain specific performance?

Overview of the Dissertation

Successful training of air traffic controllers includes both the development of domain specific competences (e.g., visual problem-solving skills) and the acquisition of self-regulation skills. The aim of this dissertation is to increase understanding of the complexity of the ATC domain (i.e., specifically visual problem-solving) and to design and test a learning environment which integrates the development of self-regulation skills in the domain-specific training. To answer the aforementioned research questions, the studies presented in this dissertation take three approaches (see Figure 1.1 for an overview). The first approach focuses on the complexity of the ATC domain by elaborating on required visual expertise and specifically on the underlying visual problem-solving strategies. The second approach focuses on self-regulation, and specifically on how SRL skills, SDL skills and self-efficacy mutually interact and what their importance is for successful ATC-training. The third approach focuses on a training design which integrates the development of the students' regulation skills with the development of domain specific ATC-competences. The training design includes shared control in the environment between the system (i.e., the trainer and the environment) and the learner. In this third approach, a practical study is also presented which deals with the implications of parts of such training design on successful training in ATC and on the development of self-regulation skills.

The four subsequent chapters aim at answering the four research questions, respectively. Chapter 2 presents a study which matches strategies for visual problem-solving with performance of novices, intermediates and experts in the ATC-domain. Eye-tracking is used to investigate eye-movements of respondents at these three levels of expertise. The use of visual problem-solving strategies such as means-end analysis, information reduction and chunking are mapped out for novices, intermediates and experts. Also the performance similarity between participants is investigated to gain insight in the influence of specific strategy use and expertise on the diversity of traffic conflict solutions found. The chapter discusses implications of differences of solution similarity and visual strategies for the use of eye-movement modeling examples in ATC training.

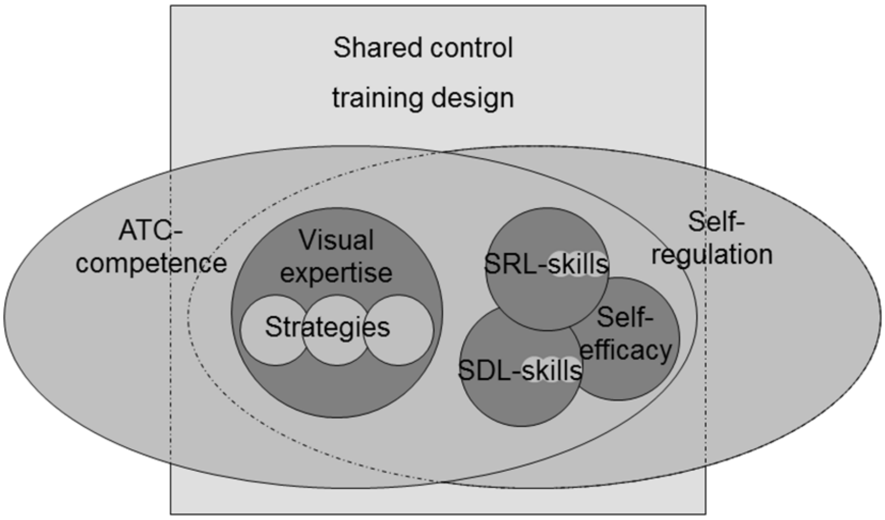

Figure 1.1 *Schematic overview of the relation between concepts in this dissertation: Shared control training design, training self-regulation, and ATC-competences.*

Chapter 3 presents a study that investigates the regulation skills required to be a successful ATC student and how cognitions of different stakeholders differ as to these requirements. This chapter employs focus groups with three different groups of stakeholders (i.e., training designers, trainers/coaches, students) to determine those skills that must be trained when preparing students to learn throughout their ATC careers. The study sheds light on the learning characteristics required for successfully learning ATC. Moreover, the chapter provides insight in the mutual relation between two groups of regulation skills: self-regulated learning (SRL; Zimmerman, 1990) and self-directed learning (SDL; Knowles, 1975, Van Merriënboer & Sluijsmans, 2009) and takes into account the mediation of student engagement and self-efficacy on SRL and SDL. The differences between cognitions of successful training in ATC give insight how instructional designers, trainees and coaches differ.

Chapter 4 presents a theoretical framework for combining the training of complex cognitive skills with the development of regulation skills. It is based on the premise that it is best to use shared control in the task selection process. This framework also deals with the paradox that a system that trains regulation skills also requires students to have already developed regulation skills (Corbalan, Van Merriënboer, & Kicken, 2010). Shared control in task selection aims at increasing the responsibility of learners for selecting their own learning tasks. This responsibility should activate the learners to think about their own learning challenges. By discussing both the system and the required attitude of coaches and students in such an environment, insight is gained with respect to the requirements for the elements (i.e., task database, portfolio) employed in it. A coaching protocol is also introduced to support the coaches in using the system's elements to involve the students in their own learning process.

Chapter 5 presents an empirical study testing the idea of training self-regulation skills in combination with domain-specific competences. The study is carried out in the everyday practice of ATC training. The chapter describes the design of learning tasks and the role of a development portfolio in such learning environments. The increase of learning in both domain-specific skills and self-regulation skills is measured.

Finally, Chapter 6 discusses the overall conclusion that can be drawn from the thesis in light of training improvements in cognitively complex domains. The chapter than discusses the theoretical and practical implications of the studies and concludes with the limitations of the studies and with ideas for future research.

CHAPTER 2

Identification of Effective Visual Problem-solving Strategies in a Complex Visual Domain

Students in complex visual domains must acquire visual problem-solving strategies that allow them to make fast decisions and come up with good solutions to real-time problems. In this study, 31 air traffic controllers at different levels of expertise (novice, intermediate, expert) were confronted with 9 problem situations depicted on a radar screen. Eye-tracking data revealed that novices use inefficient means-end visual problem-solving strategies in which they primarily focus on the destination of aircraft. Higher levels of expertise yield visual problem-solving strategies characterized by more efficient retrieval of relevant information and more efficient scan paths. Furthermore, experts' solutions were more similar than intermediates' solutions and intermediates' solutions were more similar than novices' solutions. Performance measures showed that experts and intermediates reached better solutions than novices, and that experts were faster and invested less mental effort than intermediates and novices. These findings may help creating eye-movement modeling examples for the teaching of visual problem-solving strategies in complex visual domains.

This chapter is based on: Van Meeuwen, L. W., Jarodzka, H., Brand-Gruwel, S., Kirschner, P. A., De Bock, J. J. P. R., & Van Merriënboer, J. J. G. (2013). Identification of effective visual problem-solving strategies in a complex visual domain. Manuscript submitted for publication.

In many complex cognitive domains, professionals (e.g., medical specialists, power plant controllers, pilots) make decisions on the basis of their interpretation of complex visualizations. Air traffic controllers, for example, need to interpret available visual information on a radar screen in order to guide aircraft to an airport. Students in air traffic control (ATC) must develop domain-specific visual problem-solving strategies to become experts in their domain. Process-oriented worked examples that make the cognitive processes of experts visible can help students learn to solve particular problems (Van Gog, Paas, & Van Merriënboer, 2006, 2008; Van Gog & Rummel, 2010). In visual domains, eye-movements are a direct indicator of visual expertise because they change as experience increases from novice towards expert (for overviews, see Gegenfurtner, Lehtinen, & Säljö, 2011; Gegenfurtner, Siewiorek, Lehtinen, & Säljö, 2013; Reingold & Sheridan, 2011; Spivey & Dale, 2011). So-called *eye-movement modeling examples* (EMMEs) may make the visual problem-solving process visible by superimposing an expert’s gaze pattern on the image so that the learner can study what an expert is looking at and in which order (Jarodzka, Boshuizen, & Kirschner. 2012; Jarodzka, Van Gog, Dorr, Scheiter, & Gerjets, 2013; Van Gog, Jarodzka, Scheiter, Gerjets, & Paas, 2009). However, there are open questions in terms of how to design EMMEs using experts’ eye-movements. The first question concerns the strategies for visual problem-solving used at different levels of expertise (Feldon, 2007; Jarodzka, Scheiter, Gerjets, & Van Gog, 2010). The second question is whether these strategies lead to one common solution or to a wide variety of solutions when carrying out a perceptual task (cf. Medin et al., 2006).

With regard to strategies used at different levels of expertise, at least three levels can be distinguished in the development towards expert performance (Berliner, 1986; Boshuizen & Schmidt, 2008; Dreyfus & Dreyfus, 2005): Novices are beginners in a domain without relevant experience; intermediates have experience in a domain but not reached the expert level yet, and experts show “consistently superior performance on a specified set of representative tasks for a domain” (Ericsson & Lehmann, 1996, p. 277). Most research on visual problem-solving focused on experts only or on differences between novices and experts. The number of studies using intermediates is limited (Gegenfurtner, Lehtinen, & Säljö, 2011; Reingold & Sheridan, 2011), and, thus, there is a lack of knowledge about stages in the development of visual problem-solving as well as the strategies novices, intermediates and experts use when solving visual problems. This knowledge is needed for designing example-based learning materials such as EMMEs. Moreover, it is important to know whether particular visual problem-solving strategies lead to different solutions for the same problem or not; obviously, it is more desirable to teach problem-solving strategies that lead to similar and good solutions for a wide range of problems.

This chapter aims at gaining insight in how expertise affects visual problem-solving strategies, similarity of found solutions, and performance. The next sections discuss the visual problem-solving strategies novices, intermediates and experts use when carrying out perceptual tasks; the degree to which people with different expertise levels and strategies come up with either common or different solutions for the problem at hand, and the moderating effect of task difficulty when studying the influence of expertise on visual problem-solving strategies, the similarity of solutions, and performance.

Visual Problem-Solving Strategies

When solving problems, cognitive schemas retrieved from long-term memory enable the use of problem-solving strategies (Boshuizen & Schmidt, 2008). At least three problem-solving strategies can be distinguished for solving visual problems, namely, attention focusing, chunking, and means-end analysis (Chi, Glaser, & Rees, 1982; Gobet & Simon, 1998; Haider & Frensch, 1999; Simon, 1975).

When using the strategy *attention focusing* schemas help to distinguish between relevant and irrelevant information and so enable problem solvers to focus on what is important in a given problem situation. Haider and Frensch (1999) describe in their information-reduction theory that experts optimize the amount of processed information by separating task-irrelevant from task-relevant information. This theory was supported by the findings in a meta-analysis by Gegenfurtner et al. (2011) and by Reingold and Sheridan's (2011) review of research on expertise in medicine and chess. In the field of aviation, two studies support the information-reduction theory. Kasarskis, Stehwien, Kickox, and Aretz (2001) studied scanning characteristics of novice and expert aircraft pilots during landing. They found that eye-scanning patterns and specific fixation behaviors of experts differed from those of novices. Experts showed shorter but more fixations (during fixations the eyes stand still and take in new information), more fixations on relevant points such as aim point and airspeed, and fewer fixations on less relevant points such as the altimeter because all necessary altitude information was obtainable from the true horizon. Also in a study by Bellenkens, Wickens, and Kramer (1997), expert pilots scanned more crucial instruments during a simulated flight task than novices.

The strategy of *chunking* relevant information makes it possible to combine important elements together so that they can be treated in working memory as *one* information element in a given problem situation. This requires less effort than processing all elements separately. Experts can use the chunking strategy because they use schemas formed from earlier experiences and recognize familiar compositions of task elements or ‘patterns’ (e.g., frequently occurring air traffic situations) without viewing all the details (Gobet & Simon, 1998). In ATC, the use of chunking would be manifest in less gaze switches between separate elements (e.g., aircraft), because particular groups of elements (e.g., all aircraft in a queue) are treated as one element.

The strategy that can be characterized as *means-end analysis* is based on schemas for working backward from the goal, rather than working towards the goal. This strategy is described as a highly general but effort-demanding problem-solving strategy (Simon, 1975), where the task performer uses a continuous orientation on the goal (the ‘end’) and tentatively applies operators (the ‘means’) to determine a next step in the problem-solving process that helps to move in the direction of the goal. More advanced problem solvers understand which routine of operations is underlying the final solution. Thus, they do not reason backwards from the goal but decide based on the prior act what the next act should be to reach the final goal. This sequence of actions can ultimately become automated, leading to fast and accurate performance which hardly requires the investment of mental effort (Chi et al., 1982; Sweller, 2004; Van Merriënboer, Clark, & De Croock, 2002). In a visual domain like ATC, the use of means-end analysis would be manifest by frequently focusing on the goal (e.g., the airport), whereas working-forward strategies would be manifest by frequently focusing on the elements that are affected by the problem-solving steps (e.g., the aircraft).

Similarity of Solutions

For problems in complex visual domains, there is typically not one general problem solution but a broad range of solutions that may vary from suboptimal (or even incorrect) to more optimal (Gronlund, Dougherty, Durso, Canning, & Mills, 2005; Mumford, Schultz, & Van Doorn, 2001). In ATC, for example, the number of acceptable solutions to guide the aircraft to an airport is restricted by safety rules and the need for efficiency (safety: maintaining at least five miles horizontal separation and 1000 feet vertical separation; efficiency: causing as little delays as possible), but there are many degrees of freedom in finding these solutions (e.g., you can keep enough separation between aircraft by changing either their speed, height or direction).

The level of expertise influences the ability of anticipating on possible situations (Mumford et al., 2001) resulting in more or less optimal solutions. For novices, visual problem-solving is highly demanding because they have not yet cognitive schemas available that help them organize the perceived information. Due to their limited working-memory capacity they are easily overwhelmed by the amount of information, especially when this information is transient such as in ATC (Lowe, 2003; Mayer, 2005; Scheiter, Gerjets, Huk, Imhof, & Kammerer, 2009; Spanjers, Van Gog, & Van Merriënboer, 2010; Sweller, Van Merriënboer, & Paas, 1998). As a consequence, their awareness of the current situation will be limited, incomplete and sometimes erroneous, which hampers their projection of the future status (Endsley, 1995) and thus leads to a broad range of dissimilar solutions, including many incorrect or suboptimal solutions.

Intermediates have constructed cognitive schemas that allow them to organize given information when they are confronted with visual problems, but, compared to experts they have more problems with linking their schemas to specific problem situations (Boshuizen & Schmidt, 1992; 2008). They still have difficulties with immediate pattern recognition or may be not aware that a chosen schema is not appropriate for the given problem and thus miss important details for correct decision making (for an overview, see Gegenfurtner et al., 2013). It can thus be expected that intermediates find better and more similar solutions than novices, but there will still be a notable dissimilarity across solutions because they frequently come up with less optimal solutions.

Experts possess well developed schemas for many specific situations (e.g., in ATC: “inbound traffic from the west with strong tail wind”), which help them to quickly build a good awareness of the problem situation (Schmidt, Norman, & Boshuizen, 1990; Boshuizen & Schmidt, 2008). The number of available schemas also increases experts’ repertoire for solving problems (De Groot, 1978; Ericsson & Lehmann, 1996; Gobert & Simon; 1998), resulting in a flexible range of potential problem-solving strategies (Lesgold et al., 1988). Their ability to quickly recognize a broad range of problem situations allows them to come up with optimal solutions (Endsley, 2006), and because most of these solutions are optimal they can be expected to be relatively similar. If any differences occur, these will be marginal and based on personal preferences.

Performance and Task Difficulty

A better understanding of visual problem-solving strategies and similarity of solutions will help to explain differences in performance between experts, intermediates and novices. Such performance differences have been well documented in literature, showing that experts outperform intermediates and novices, and intermediates outperform novices. First, higher expertise is associated with higher accuracy and reaching more optimal solutions (Ericsson, 2006). Second, higher expertise is associated with faster performance or speed, meaning that experts not only reach better solutions but also do this in less time (Lesgold et al., 1988). Third, experts have better developed schemas allowing them to make changes already early which means that they prevent conflicts later in the process, resulting in lower mental effort during task performance (Sweller et al., 1998).

Performance differences between experts, intermediates and novices may not show for all levels of task difficulty (in ATC: amount of aircraft that must be controlled, potential conflicts, weather conditions). For example, novices and intermediates may perform equally well on very easy tasks, while intermediates and experts may perform equally well on tasks at a medium level of difficulty. Thus, it is important to compare expertise levels across tasks with different difficulty levels, and performance differences between experts, intermediates, and novices may become more visible as tasks become more difficult. Furthermore, eye-movements and visual problem-solving strategies may also vary as a function of task difficulty (cf. Gegenfurtner et al., 2011). Less experienced problem solvers are not yet able to ignore irrelevant information, chunk related elements and work forward, which causes conflicts with the limited capacity of processing capacity available, especially for more difficult tasks (Mayer, 2005; Mayer & Moreno, 2003). Therefore, differences in visual problem-solving strategies and similarities of solutions between experts, intermediates and novices are also expected to become more visible in more difficult tasks.

Hypotheses

Experts, intermediates and novices are expected to use different visual problem-solving strategies and will thus show different eye-movements (Hypothesis 1). First, experts will have a better information-reduction strategy resulting in more eye-fixations on relevant areas of interest and shorter times to the first fixation on these relevant areas of interest compared to intermediates and novices (Hypothesis 1a). Second, experts will have a better chunking strategy resulting in less gaze switches between single elements (e.g., they deal with groups of aircraft rather than a single aircraft) and thus more efficient scan paths compared to intermediates and novices (Hypothesis 1b). Third, experts will not use means-end analysis but a working-forward strategy, resulting in less eye-fixations on the destination point of the aircraft compared to intermediates and novices (Hypothesis 1c).

Furthermore, experts are expected to reach more similar task solutions than intermediates, and both experts and intermediates are expected to reach more similar solutions than novices (Hypothesis 2).

For the quality of performance, experts are expected to reach better solutions in less time and to invest less mental effort than intermediates, and both experts and intermediates are expected to reach better solutions in less time and to invest less mental effort than novices (Hypothesis 3).

Finally, the differences between experts, intermediates and novices are expected to be more pronounced for relatively difficult tasks than for easy tasks, yielding interactions between level of expertise and task difficulty (Hypothesis 4).

Method

Participants

Participants in the study were 31 participants (*M* = 26.45 years, *SD* = 6.31; 8 females and 23 males) with three different levels of expertise. Experts were ten fully licensed air traffic controllers whom had worked for at least two years (years of work experience: *M* = 7.10, *SD* = 6.83; age: *M* = 33.10 years, *SD* = 6.81). Intermediates were nine students in the final phase of the regular on-the-job-training program for air traffic controllers (months of training: *M* = 22.33, *SD* = 6.20; age: *M* = 24.67 years, *SD* = 2.18). Novices were 12 students in the initial phase of the ATC training program (months of training: *M* = 3.25, *SD* = 0.45; age: *M* = 22.25, *SD* = 2.30).

Materials and Apparatus

Air traffic control tasks. Nine tasks with three difficulty levels (i.e., three easy, three medium, and three difficult tasks) were composed using still pictures of realistic ATC radar situations. The three levels of difficulty were determined a priori, depending on the number of aircraft involved and the number of conflicts ahead. The tasks were composed by a domain expert in ATC and involved a number of inbound aircraft heading towards the initial approach fix “Artip” of Amsterdam Airport Schiphol (see Figure 2.1). Artip is the route junction and initial approach fix that aircraft need to cross (i.e., the ‘goal’). For each task, participants had to determine the optimal order of arrival at Artip of the aircraft that had to be controlled (e.g., KLM078, KLM1234, TRA321, JAP411 etc.). Three sets of tasks were composed and each set comprised three of the nine tasks. A set started with an easy task, followed by a medium task, and finally a difficult task. The order of the sets was counterbalanced between participants.

Stills of ATC radar situations were used to create constrained processing tasks (cf. Hoffman, 1987), suitable for conducting analyses on the initial phase of the control process. In ATC, in the initial phase situational awareness is built to decide on the optimal order of arrival of the aircraft (Oprins & Schuver, 2003). Moreover, the analysis of stills allows for the use of fixation parameters in eye-tracking data.

Mental effort. For each task the perceived mental effort was measured using the scale developed by Paas (1992). Participants indicated their perceived mental effort after accomplishing the task on a 9-point Likert scale ranging from 1 (“very, very low effort”) to 9 (“very, very high effort”).

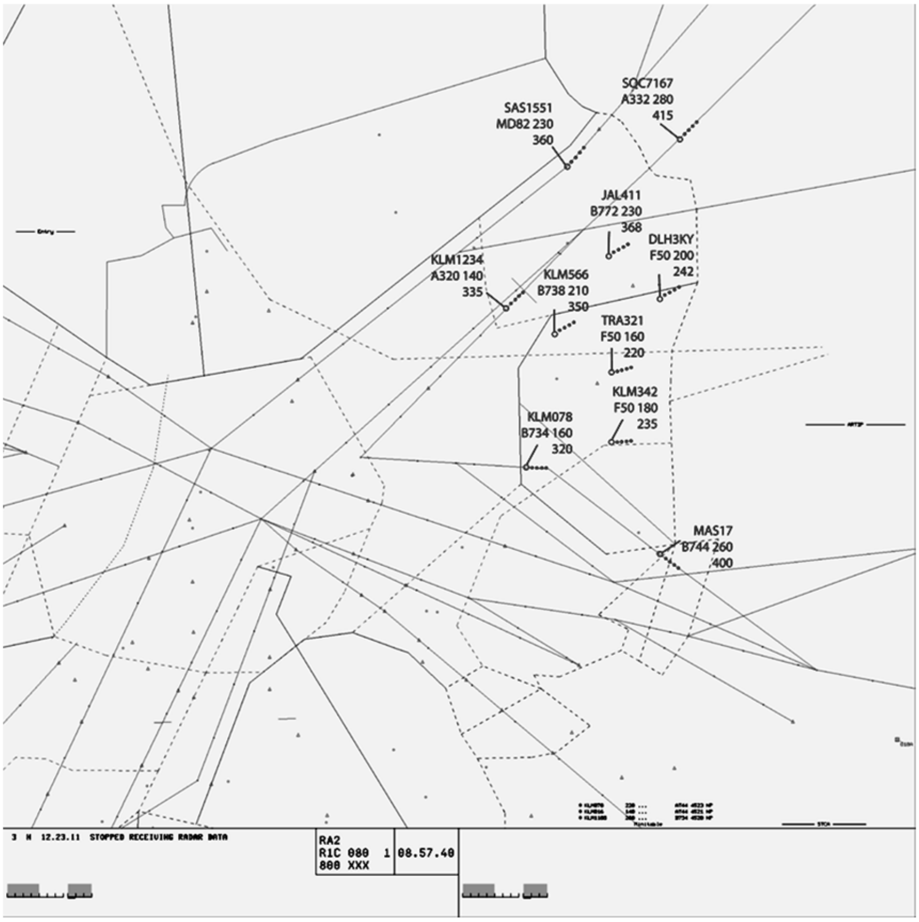

Figure 2.1 *Negative of example screenshot of an ATC radar screen. The ATC controller has to determine the optimal order of arrival of the aircraft to the initial approach fix Artip.*

Eye-tracking. Because the use of strategies is based on visual information, eye-tracking is a plausible technique to provide evidence on the strategies used when carrying out perceptual tasks. Eye-tracking research distinguishes between *fixations* and *saccades* (Holmqvist et al., 2011). During fixations the eyes stand still and can take in new information. Saccades are the eye-movements from one fixation to another. During saccades, the information transfer is suppressed but the focus of attention moves from one element to another element. Saccades between several areas are also referred to as *transitions*.

The still ATC pictures were presented on a 17” (43 cm) diagonal screen (1280 * 1024 pixels). During task performance, eye-movements of participants were recorded with a Tobii 1750 remote eye-tracking system with a temporal resolution of 50 Hz. Eye-movement data were recorded and processed with Tobii Studio 2.1 software using the standard Tobii fixation filter algorithm (settings: 35 velocity x 35 dispersion).

Procedure

The experiment was run in individual sessions of approximately 60 minutes. First the participants answered some demographic questions. Subsequently, participants received the following instructions: “You will see nine radar-ATC situations. Please execute the following task: Determine the preferred order of arrival at point Artip and report this order out loud. Work as safe, as efficient, and as fast as possible”. After the warming-up task in which Artip was indicated, the nine still pictures of ATC radar situations were presented to the participants. After each task, participants indicated their perceived mental effort.

Data Analysis

Analysis of visual strategies. To assign eye-tracking data to an element or region on the screen, each still ATC picture was divided into areas of interest (AOI). Visual inspection of the eye-tracking data yielded insight in the minimal size of the AOIs. Each AOI initially had the same size and either covered the radar plot, the trail indicated with dots, the label of a single aircraft, or Artip. In situations where aircraft were close to each other, the related AOIs overlapped. In such cases, the overlapping AOIs were equally reduced in size until they were exactly adjacent to each other (for an example, see Figure 2.2).

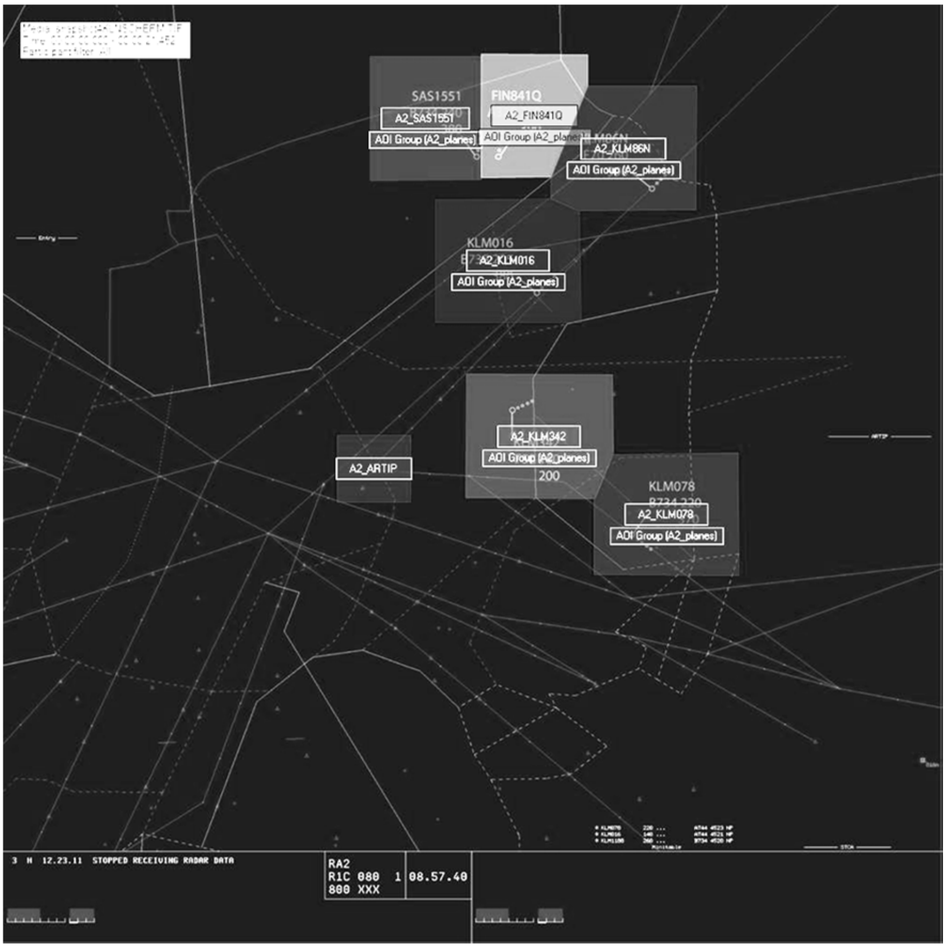

Figure 2.2 ***Examples of Areas of Interest (AOIs) around aircraft and Artip. Size of the AOIs is determined by the average size and shape of an eye-tracking heat map. The AOIs around the aircraft were adjusted in size to not overlap each other.***

The following eye-tracking measures were derived per AOI: Total fixation duration (i.e., total time spent looking at a certain area on the screen), time until first fixation (i.e., the time until the participant looked at a certain area on the screen for the first time from stimulus onset), and AOI transition matrices (i.e., indicators for how often participants switched their gaze from one AOI to another AOI). Because time-on-task differed across participants, also the total fixation duration did. Hence, to make this fixation duration comparable across participants and across tasks, the sum of total fixation durations on AOIs and non-AOI areas was standardized by dividing each sum by the individual time spent on task. This resulted in *relative* fixation duration measures. Missing values (i.e., no visit on AOI) were replaced by zero. In case of no visit on AOI, no time to first fixation was recorded either. Hence, to make this eye-tracking parameter comparable across participants, missing values were replaced by the maximum time-on-task across participants (see for a description of the same procedure, Jarodzka et al., 2010). To obtain transition matrices, individual strings of all fixation locations were exported from Tobii Studio and transformed per ATC task into matrices. These matrices comprised per task the number of transitions for each participant between and within all different AOIs. Per task and per participant the total number of transitions between different aircraft and the total number of transitions within aircraft were computed. Per task only one AOI covered Artip and the background area was defined as the area not being covered by an AOI (i.e., non-AOI area). Finally, the total number of transitions between aircraft and background, aircraft and Artip, and background and Artip were computed.

Analysis of similarity of task solutions. Two experts blindly and independently scored all performances on one of the difficult tasks (i.e., more than 10% of the tasks). They subtracted one point from the maximum of five points for each unrealistic order of aircraft resulting in a *task correctness* score. The maximum number of points subtracted was five so that the scores ranged between 0 and 5. They achieved a high inter-rater reliability: Spearman rank correlation $\rho = .846$ ($p < .001$). The remaining tasks were scored by only one of the experts.

The similarity of task solutions was calculated by means of sequence analyses based on the so-called Levenshtein distances (Levenshtein, 1966). The Levenshtein distance is a measure for difference between two sequences. It is obtained by the minimal number of operations needed to transfer one sequence into another sequence. The possible operations are insertions, deletions, or substitutions of single characters. To determine the Levenshtein distance in the present study, a string of aircraft that a participant determined in a given order (e.g., KLM078, KLM1234, TRA321, JAP411, …) served as the input data. The number of operations (i.e., insertions or deletions of aircraft) needed to transform the aircraft sequence of this participant into that of another participant describes the difference between the two sequences of aircraft. The Levenshtein distance was determined for the aircraft sequences of experts, intermediates and novices to analyze the similarity of task solutions used within these groups. This procedure resulted in a similarity score for each possible pair of experts, intermediates, and novices.

For all analyses a factorial repeated-measures ANOVA is used with levels of expertise (i.e., novice, intermediate, expert) as between-subjects factor and difficulty (i.e., easy, medium, and difficult) as within-subjects factor. A significance level of .05 is used for all reported analyses. To test the hypotheses, the main effects of expertise level and task difficulty and their interaction are reported. In case of a significant effect, Bonferroni post-hoc tests are conducted. Because of problems with sphericity, the results of the Greenhouse Geisser contrast analysis are given.

Results

Visual Problem-solving Strategies

Means and standard deviations of all eye-tracking measures are presented in Table 2.1.

Fixation duration. To test Hypotheses 1a (i.e., information reduction strategy) and 1b (i.e., chunking strategy), the *relative fixation duration on aircraft, relative fixation duration on Artip,* and *relative fixation duration on the background area* were analyzed. Relative fixation durations are given as percentage of time-on-task.

Results showed no main effect of expertise level on relative fixation duration on aircraft, $F(2, 29) = 1.240$, $MSE = 16.146$, $p = .305$, $\eta_p^2 = .081$, but it showed a main effect of task difficulty, $F(2, 58) = 32.02$, $MSE = 36.73$, $p < .001$, $\eta_p^2 = .534$. Post-hoc tests revealed that relative fixation duration on aircraft in easy tasks was significantly shorter than in medium tasks ($p = .015$), and that relative fixation duration on aircraft in both easy tasks and medium tasks was shorter than in difficult tasks (both p-values $< .001$). No interaction effect was found between expertise level and task difficulty on relative fixation duration on aircraft, $F(4, 58) = 2.45$, $MSE = 36.37$, $p = .060$, $\eta_p^2 = .149$.

Table 2.1 *Means and Standard Deviations*

	Experts			Intermediates			Novices		
	Easy	Medium	Difficult	Easy	Medium	Difficult	Easy	Medium	Difficult
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Eye-tracking									
Relative Fixation Duration Aircraft (% Total time-on-task)	88.86 (4.18)	89.81 (5.31)	94.27 (3.50)	86.01 (6.73)	86.77 (8.89)	91.87 (4.28)	85.17 (4.13)	91.40 (3.21)	94.65 (2.00)
Relative Fixation Duration on Artip (% Total time-on-task)	0.06 (0.14)	0.01 (0.04)	0.06 (0.15)	0.23 (0.49)	0.16 (0.27)	0.04 (0.08)	1.25 (1.09)	0.64 (0.71)	0.43 (0.45)
Relative fixation Duration on Background area (% Total time-on-task)	3.27 (3.17)	5.33 (5.94)	2.49 (2.06)	10.40 (7.36)	11.96 (10.26)	6.19 (4.30)	10.20 (3.89)	5.61 (3.05)	2.75 (1.23)
Time to First Fixations on Aircraft (Sum of Time to First Fixations on Aircraft in seconds)	22.65 (6.01)	21.30 (7.23)	80.82 (22.57)	24.02 (6.58)	32.22 (6.55)	107.56 (21.43)	30.02 (8.97)	34.65 (9.51)	130.50 (39.24)
Time to First Fixations on Artip (in seconds)	30.07 (3.01)	40.90 (4.00)	44.18 (6.18)	28.70 (6.16)	34.39 (12.56)	46.78 (0.26)	18.28 (10.24)	29.16 (13.68)	28.68 (19.83)
Transitions Artip – Aircraft	0.10 (0.16)	0.03 (0.11)	0.07 (0.21)	0.260 (0.32)	0.11 (0.17)	0.70 (1.42)	0.81 (0.70)	0.72 (0.68)	1.36 (1.66)
Transitions Aircraft (X) – Aircraft (Y)	8.83 (3.32)	17.90 (7.99)	46.13 (14.70)	11.00 (3.17)	20.93 (6.34)	53.96 (13.46)	13.28 (3.83)	27.140 (9.70)	55.50 (18.33)
Transitions Artip – Background	0.03 (0.11)	0.00 (0.00)	0.13 (0.28)	0.07 (0.22)	0.11 (0.24)	0.07 (0.15)	0.47 (0.50)	0.33 (0.47)	0.22 (0.26)
Transitions Background – Aircraft	1.37 (0.90)	3.30 (2.43)	4.27 (3.16)	4.70 (2.93)	9.93 (6.99)	9.52 (5.12)	6.67 (3.44)	7.31 (3.99)	6.32 (3.79)
Similarity									
Similarity of Task Solutions	.96 (.09)	.59 (.17)	.23 (.07)	.91 (.11)	.47 (.19)	.21 (.05)	.71 (.19)	.40 (.16)	.18 (.04)
Performance									
Task Correctness Score	4.97 (0.11)	4.83 (0.28)	4.08 (0.79)	4.78 (0.55)	4.48 (0.63)	3.65 (0.79)	4.53 (0.61)	3.97 (0.56)	2.97 (0.942)
Time-on-task	9.51 (2.36)	16.28 (2.98)	31.19 (5.65)	12.26 (2.78)	21.85 (4.06)	40.28 (6.70)	16.23 (4.45)	25.79 (6.55)	44.76 (8.71)
Perceived Mental Effort	2.00 (0.70)	3.80 (1.06)	5.30 (1.44)	3.41 (1.01)	4.78 (0.76)	6.07 (0.85)	3.19 (0.89)	4.39 (0.57)	5.56 (0.50)

Results showed a main effect of expertise level on relative fixation duration on Artip, *F*(2, 29) = 8.96, *MSE* = .19, *p* = .001, η_p^2 = .39, as well as a main effect of task difficulty, *F*(2, 58) = 6.88, *MSE* = .617, *p* = .008, η_p^2 = .197. Post-hoc tests in expertise levels revealed that novices fixated longer on Artip than both intermediates (*p* = .009) and experts (*p* = .002). Post-hoc tests in task difficulty revealed that relative fixation duration on Artip in easy tasks was shorter than in difficult tasks (*p* = .024). Moreover, results showed an interaction effect between expertise level and task difficulty, *F*(4, 58) = 4.174, *MSE* = .617, *p* = .015, η_p^2 = .230 (see Figure 2.3a). Post-hoc tests revealed that on easy tasks novices fixated longer on Artip than both experts (*p* = .001) and intermediates (*p* = .002); on medium tasks, novices fixated longer on Artip than experts (*p* = .015), and on difficult tasks novices fixated longer on Artip than both experts (*p* = .010) and intermediates (*p* = .010).

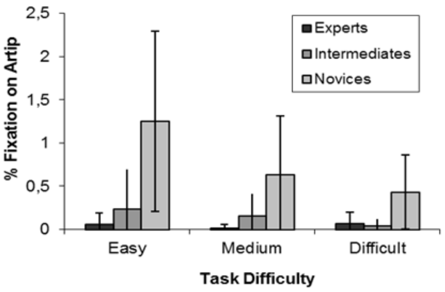

Figure 2.3a *Means and standard deviations of fixation duration on Artip by experts, intermediates and novices in easy, medium and difficult tasks.*

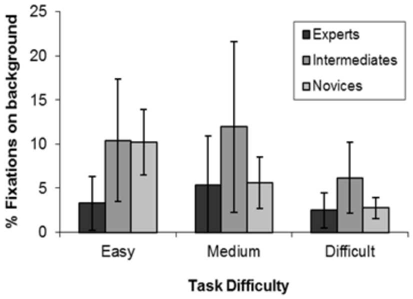

Figure 2.3b *Means and standard deviations of fixation duration on the background area by experts, intermediates and novices in easy, medium and difficult tasks.*

Results showed a main effect of expertise level on relative fixation duration on the background area, *F*(2, 29) = 4.03, *MSE* = 19.94, *p* = .029, η_p^2 = .224, as well as a main effect of task difficulty, *F*(2, 58) = 30.51, *MSE* = 122.32, *p* < .001, η_p^2 = .521. Post-hoc tests between expertise levels revealed that intermediates fixated longer on the background area than experts (*p* = .025), while novices did not differ from intermediates (*p* = .307) and experts (*p* = .609). Post-hoc tests between task difficulty levels revealed that relative fixation duration on the background area in easy tasks was significantly longer than in both medium and difficult tasks (both *p*-values < .001). Moreover, results showed an interaction effect between expertise level and task difficulty, *F*(4, 58) = 5.835, *MSE* = 28.791, $p = .001$, $\eta_p^2 = .294$ (see Figure 2.3b). Post-hoc tests revealed that on easy tasks experts fixated less on the background area than both intermediates ($p = .012$) and novices ($p = .009$). On difficult tasks, intermediates fixated more on the background area than both experts ($p = .017$) and novices ($p = .022$).

Time to first fixation. To further test Hypothesis 1a (i.e., information reduction strategy), the *time to first fixation on aircraft* and *time to first fixation on Artip* were analyzed.

Results showed a main effect of expertise level on time to first fixation on aircraft, $F(2, 29) = 8.21$, *MSE* = 158.44, $p = .002$, $\eta_p^2 = .37$, as well as a main effect of task difficulty, $F(2, 58) = 327.32$, *MSE* = 1402.47, $p < .001$, $\eta_p^2 = .921$. Post-hoc tests between expertise levels revealed that novices took significantly more time than experts to first fixate on aircraft ($p = .001$), while intermediates did not differ from novices ($p = .334$) and experts ($p = .109$). Post-hoc tests between task difficulty levels revealed that time to first fixation on aircraft in difficult tasks was longer than in both medium tasks and easy tasks, and longer in medium tasks than in easy tasks (all *p*-values < .001). Moreover, results showed an interaction effect between expertise level and task difficulty, $F(4, 58) = 6.813$, *MSE* = 1402.47, $p = .003$, $\eta_p^2 = .327$ (see Figure 2.4). Post-hoc tests revealed that in medium tasks, experts showed a shorter time to first fixation on aircraft than both intermediates ($p = .019$) and novices ($p = .002$), and in difficult tasks, experts showed a shorter time than novices ($p = .002$).

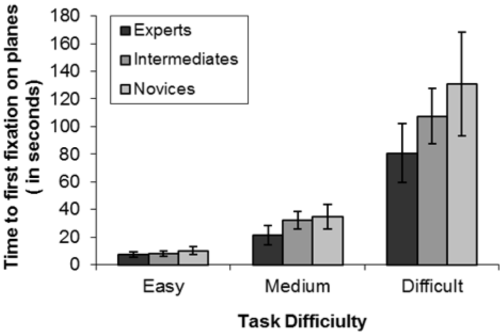

Figure 2.4 *Means and standard deviations of time to first fixation on aircraft by experts, intermediates and novices in easy, medium, and difficult tasks.*

Results also showed a main effect of expertise level on time to first fixation on Artip, *F*(2, 29) = 8.00, *MSE* = 69.02, *p* = .002, η_p^2 = .364, as well as a main effect of task difficulty, *F*(2, 58) = 22.852, *MSE* = 248.82, *p* < .001, η_p^2 = .449. Post-hoc tests between expertise levels revealed that novices took less time to first fixate on Artip than both intermediates (*p* = .014) and experts (*p* = .003), while intermediates and experts did not differ from each other (*p* = 1.00). Post-hoc tests between task difficulty levels revealed that time to first fixation on Artip in easy tasks is shorter than in medium tasks and difficult tasks (both *p*-values < .001). No interaction effect was found between expertise level and task difficulty, *F*(4, 58) = 1.623, *MSE* = 46.75, *p* = .192, η_p^2 = .104.

Transitions. To test Hypothesis 1c (i.e., means-end analysis) and to further test Hypothesis 1b (i.e., chunking strategy), the number of transitions between *Artip and aircraft*, *different aircraft* (e.g., Aircraft X – Aircraft Y), *Artip and background* (e.g., Artip – some white space around Artip or around the aircraft), and *background and aircraft* were analyzed.

Results showed a main effect of expertise level on number of transitions between *Artip and aircraft*, *F*(2, 29) = 6.78, *MSE* = .34, *p* = .004, η_p^2 = .33, but no main effect of task difficulty, *F*(2, 58) = 3.396, *MSE* = 2.085, *p* = .065, η_p^2 = .108. Post-hoc tests between expertise levels revealed that experts used less transitions between Artip and aircraft than novices (*p* = .004), while experts and intermediates (*p* = .861) as well as novices and intermediates (*p* = .079) did not differ significantly from each other. No interaction effect was found, *F*(4, 58) = 1.768, *MSE* = .174, *p* = .149, η_p^2 = .112.

Results showed no main effect of expertise level on number of transitions between different aircraft, *F*(2, 29) = 2.06, *MSE* = 78.07, *p* = .146, η_p^2 = .13, but showed a main effect of task difficulty, *F*(2, 58) = 272.73, *MSE* = 254.81, *p* < .001, η_p^2 = .907. Post-hoc tests between task difficulty levels revealed that the number of transitions between different aircraft in easy tasks was less than in both medium and difficult tasks, and also less in medium tasks than in difficult tasks (all *p*-values < .001). No interaction effect was found, *F*(4, 58) = .794, *MSE* = 254.81, *p* = .479, η_p^2 = .054.

Results showed a main effect of expertise level on number of transitions between Artip and background, *F*(2, 29) = 5.08, *MSE* = .054, *p* = .013, η_p^2 = .27, but no main effect of task difficulty, *F*(2, 58) = .403, *MSE* =.174, *p* = .668, η_p^2 = .014. Post-hoc tests between expertise levels revealed that experts showed fewer transitions between Artip and background than novices (*p* = .023). Intermediates and novices (*p* = .056) and experts and intermediates (*p* = 1.00) did not differ significantly. No interaction effect was found, *F*(4, 58) = .794, *MSE* = 254.81, *p* = .479, η_p^2 = .054.

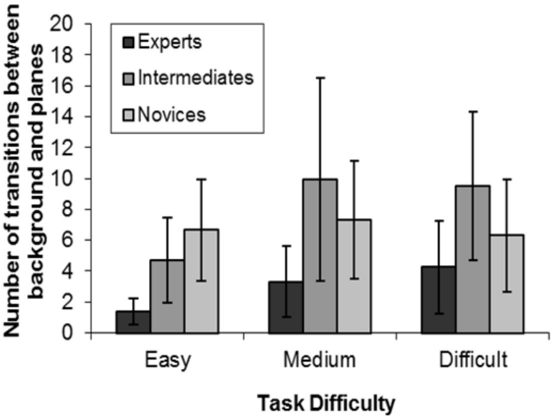

Figure 2.5 *Means and standard deviations of transitions between the background area and aircraft by experts, intermediates and novices in easy, medium and difficult tasks.*

Finally, results showed a main effect of expertise level on number of transitions between background and aircraft, *F*(2, 29) = 6.71, *MSE* = 10.13, *p* = .004, η_p^2 = .32, as well as a main effect of task difficulty, *F*(2, 58) = 8.430, *MSE* = 25.546, *p* = .001, η_p^2 = .231. Post-hoc tests between expertise levels revealed that experts used fewer transitions between background and aircraft than both intermediates (*p* = .005) and novices (*p* = .029), while intermediates and novices did not differ significantly from each other (*p* = 1.00). Post-hoc tests between task difficulty levels revealed that the number of transitions between background and aircraft in easy tasks was smaller than in both medium tasks and difficult tasks (both *p*-values = .002). Moreover, an interaction effect was found between expertise level and task difficulty, *F*(4, 58) = 29.98, *MSE* = 25.545, *p* = .031, η_p^2 = .176 (see Figure 2.5). Post-hoc tests revealed that on easy tasks experts showed less transitions between background and aircraft than both intermediates (*p* = .037) and novices

($p < .001$). Experts also showed less transitions than intermediates in medium tasks ($p = .014$) and difficult tasks ($p = .026$).

Similarity of Task Solutions

To test Hypothesis 2 (i.e., similarity) the *similarity of task solutions* was analyzed. Results showed a main effect of expertise level on similarity, $F(2, 156) = 62.24$, $MSE = .006$, $p < .001$, $\eta_p^2 = .444$, as well as a main effect of task difficulty, $F(2, 312) = 870.35$, $MSE = .059$, $p < .001$, $\eta_p^2 = .848$. Post-hoc tests between expertise levels revealed that experts were more similar to each other in performing the tasks than intermediates ($p = .003$), and both experts and intermediates were more similar to each other than novices (both p-values < .001). Post-hoc tests between task difficulty levels revealed that similarity of task solutions in easy tasks was higher than in medium and difficult tasks, and in medium tasks more similar than in difficult tasks (all p-values < .001). Moreover, results showed an interaction effect between expertise level and task difficulty, $F(4, 312) = 10.63$, $MSE = .\ 059$, $p < .001$, $\eta_p^2 = .120$ (see Figure 2.6). Post-hoc tests revealed that on easy tasks novices were less similar than both intermediates and experts (both p-values < .001). On medium tasks experts were more similar than both intermediates ($p = .008$) and novices ($p < .001$). On difficult tasks novices were less similar than both intermediates ($p < .001$) and experts ($p = .003$).

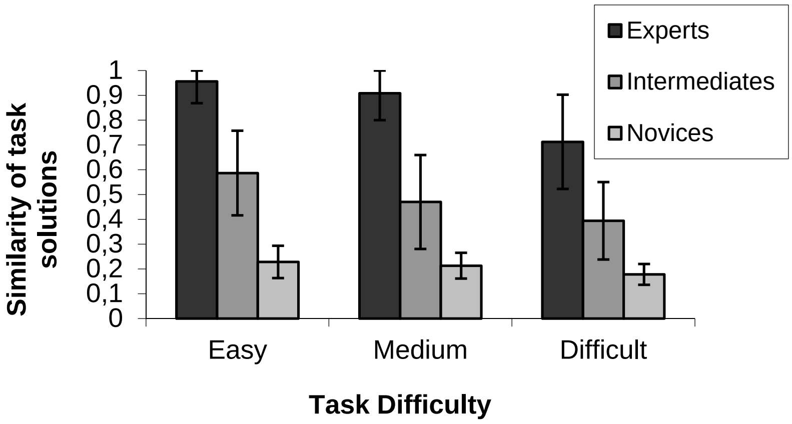

Figure 2.6 *Means and standard deviations of similarities between the chosen task solutions by experts, intermediates and novices in easy, medium and difficult tasks.*

Performance

To test Hypothesis 3 (i.e., performance), *task correctness score, time-on-task* and *perceived mental effort* were analyzed. Results showed a main effect of expertise level on task correctness score, $F(2, 29) = 13.56$, $MSE = 0.13$, $p < .001$, $\eta_p^2 = .49$, as well as a main effect of task difficulty, $F(2, 58) = 27.85$, $MSE = 1.298$, $p < .001$, $\eta_p^2 = .499$. Post-hoc tests between expertise levels revealed that novices scored significantly lower than both experts ($p < .001$) and intermediates ($p = .018$), while experts and intermediates did not differ significantly from each other ($p = .187$). Post-hoc tests between task difficulty levels revealed that task correctness scores in difficult tasks were lower than in medium tasks and easy tasks (both p-values $< .001$). No interaction effect between expertise level and task difficulty was found, $F(4, 58) = 0.788$, $MSE = 1.298$, $p = .533$, $\eta_p^2 = .053$.

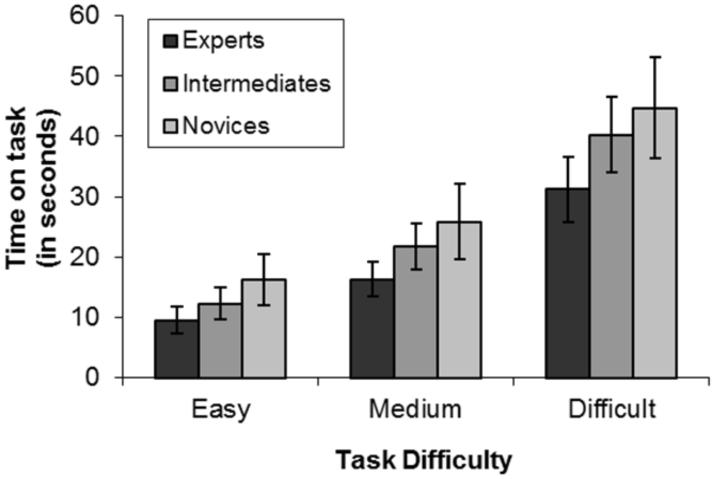

Figure 2.7 *Means and standard deviations of total time-on-task by experts, intermediates and novices in easy, medium and difficult tasks.*

Results showed a main effect of expertise level on time-on-task, $F(2, 29) = 11.67$, $MSE = 23,12$, $p < .001$, $\eta_p^2 = .455$, as well as a main effect of task difficulty, $F(2, 58) = 3.838$, $MSE = 34.029$, $p = .012$, $\eta_p^2 = .215$. Post-hoc tests between expertise levels revealed that experts performed the tasks significantly faster than both novices ($p < .001$) and intermediates ($p = .042$), while novices and intermediates did not differ significantly from each other ($p = .184$). Post-hoc tests between task difficulty levels revealed that time on task on easy tasks was shorter than on both medium and difficult tasks, and also shorter on medium tasks than on difficult tasks (all *p*-values < .001). Moreover, results showed an interaction effect between expertise and difficulty level, $F(4, 58) = 3.84$, $MSE = 34.03$, $p = .012$, $\eta_p^2 = .215$ (see Figure 2.7). On easy tasks novices took longer than both experts ($p < .001$) and intermediates ($p = .042$). On medium tasks experts were faster than novices ($p < .001$). On difficult tasks experts were faster than both novices ($p = .033$) and intermediates ($p < .001$).

Finally, results showed a main effect of expertise level on perceived mental effort, $F(2, 29) = 5.16$, $MSE = .53$, $p = .012$, $\eta_p^2 = .27$, as well as a main effect of task difficulty, $F(2, 58) = 150.914$, $MSE = 1.922$, $p < .001$, $\eta_p^2 = .844$. Post-hoc tests between expertise levels revealed that experts perceived less mental effort in performing the tasks than intermediates ($p = .011$), while, unexpectedly, experts and novices ($p = .115$) as well as intermediates and novices ($p = .767$) did not differ significantly from each other. Post-hoc tests between task difficulty levels revealed that perceived mental effort in easy tasks was lower than in medium and difficult tasks, and in medium tasks was lower than in difficult tasks (all *p*-values < .001). No interaction effect between expertise level and task difficulty was found, $F(4,58) = 1.616$, $MSE = 3.107$, $p = .210$, $\eta_p^2 = .104$.

Discussion

The main aim of this study was to investigate expertise differences in visual problem-solving strategies and the similarity of task solutions reached at different levels of expertise. Novices, intermediates and experts worked on nine ATC tasks at three levels of difficulty. First, we expected to find differences in eye-movements related to three visual problem-solving strategies: Information reduction, chunking, and means-end analysis. Second, we expected to find differences between expertise levels in the similarity of reached task solutions. Third, we ascertained that performance (i.e., correctness, speed, and perceived mental effort) was indeed different between the three expertise levels. Fourth, we investigated whether task difficulty moderated the effects of expertise.

Our results clearly support the assumption that experts, intermediates and novices apply different visual problem-solving strategies (Hypothesis 1). First, there was more information reduction for higher levels of expertise (Hypothesis 1a). Novices focused much faster and longer on Artip than intermediates and experts; for intermediates and experts, Artip seems to be an irrelevant area because they simply “know where the goal is”. Furthermore, novices took more time before they first fixated on aircraft. This indicates that they have trouble finding the relevant areas and fixate on irrelevant areas before finding the relevant ones.

Second, experts showed more chunking of related elements than intermediates and novices (Hypothesis 1b). For experts, fewer transitions between aircraft and the background area were found than for both intermediates and novices. In addition, experts spent less time looking at the background area than intermediates. Thus, experts seem to recognize familiar patterns of task elements (i.e., grouped aircraft) and need to orientate themselves less on the space surrounding these elements to effectively deal with them. These findings clearly demonstrate superior chunking strategies for experts.

Third, experts seem to use a working-forward rather than means-end strategy (Hypothesis 1c). They showed fewer transitions that included the destination point of the aircraft (i.e., Artip-aircraft and Artip-background) than novices. This indicates that novices frequently focus on the ‘goal’ in order to reach a solution, while experts develop a solution without paying attention to the goal. For intermediates, the number of transitions including Artip is in between that of experts and novices. This suggests a more or less linear development from a means-end strategy to a working-forward strategy.

With regard to the similarity of solutions, our results show that solutions of experts are more similar to each other than solutions of intermediates, and that solutions of intermediates are more similar to each other than solutions of novices (Hypothesis 2). Thus, experts recognize a broad range of problem situations which allows them to come up with optimal solutions that are relatively similar across different experts; they all work towards a comparable pre-sorted order of arrival. Intermediates recognize less problem situations and/or have more difficulties to link these situations to their decisions, and novices apply weak problem-solving methods such as means-end analysis, both leading to less similarity of their solutions (cf. Medin et al., 2006). This is an important finding because it suggests that it is worthwhile to teach expert strategies, not only because they are more effective in reaching high performance but also because they are univocal compared to non-expert strategies. Our findings add to earlier findings by Jarodzka et al. (2010) and Medin, Lynch, Coley, and Atran (1997), showing that higher expertise is related to higher similarity in reached solutions.

Experts and intermediates showed better and faster performance than novices (Hypothesis 3). However, the differences between experts and intermediates were not significantly different although in the expected direction. Possibly, the whole set of tasks was not complex enough to reveal performance differences between intermediates, who were nearly certified air traffic controllers, and experts. For perceived mental effort, an unexpected finding is that the effort reported by intermediates is not only higher than that of experts but also than that of novices. On the one hand, this fits the assumption that intermediates may have the knowledge needed to carry out the given tasks but, compared to experts, lag behind in their strategies of efficient information retrieval from the scene (i.e., chunking). On the other hand, it indicates that novices not only used less effective but also less effort-demanding strategies than intermediates. As a speculation, they experienced the tasks as so difficult that they were not inclined to invest a high level of mental effort.

Finally, the findings concerning the moderating effects of task difficulty (Hypothesis 4) are equivocal. As expected, the differences between expertise levels are for some of the measures more pronounced for difficult tasks than for easy tasks. For time to first fixation on aircraft, the differences between expertise levels are larger for difficult tasks than for easy tasks; for difficult tasks, expert are quicker than intermediates and intermediates are quicker than novices. For similarity of solutions, similarity decreases somewhat for experts and intermediates as tasks become more complex, but it is consistently low for novices. And for time on task, the difference between novices and experts is smaller for easy tasks than for more difficult tasks. Taken together, these findings suggest that the superior visual problem-solving strategies of experts and, to a lesser degree, intermediates yield a greater advantage when working on more difficult tasks.

Yet, some interactions yielded unexpected patterns. Compared to intermediates and experts, novices fixated less on Artip and less on the background area as tasks became more difficult. This indicates that for difficult tasks, novices lose the destination out of sight and seem to become less aware of the whole situation. In other words, the difficult tasks seem to be ‘too difficult’ for the novices, which is also evidenced by their low performance and, as speculated above, their low readiness to invest effort in performing the task. In addition, it is in line with the findings for transitions between background area and aircraft. Experts show more transitions, and thus more awareness of the problem situation as tasks become more difficult; intermediates only show this increase from easy to difficult tasks, and novices do not show such an increase at all.

To summarize, the use of eye-tracking made it possible to unravel the visual problem-solving strategies that experts, intermediates and novices use when solving perceptual problems in the complex domain of air traffic control. First, the development of information reduction abilities as described by Haider and Frensch (1999) was demonstrated by faster and longer fixations on relevant areas as expertise increases. Second, the development of schemas that chunk elements together (Gobet & Simon, 1998) was confirmed by more efficient scan paths as expertise increases. The higher investment of mental effort by intermediates reflects the difficulties they encounter with linking the applicable cognitive schemas to the situation at hand (Boshuizen & Schmidt, 2008). Third, the change from a means-end approach to a working-forward approach (Simon, 1975) became evident by focusing less on the final destination point (Artip) as expertise increases. Furthermore, reached solutions became more similar with higher expertise and the more effective strategies of experts often had greater value for more difficult tasks.

Our findings indicate two issues that need to be further investigated. First, limited differences in performance were found between intermediates and experts. Future research should contain more complex tasks to create situations in which experts perform significantly higher than intermediates. Such more complex tasks may also be more suitable to unravel their full scale of expertise. Higher levels of complexity could, for example, be obtained by using dynamic traffic situations rather than the stills as used in this study. Second, future research should aim to explain our unexpected findings for novices, in particular, their low investment of mental effort. It should test our speculation that tasks were experienced as too difficult by them, leading to a motivational problem and “unwillingness” to invest high effort in solving the visual problems.

With regard to theoretical implications, the cognitive theories used to predict our findings turned out to be directly applicable for some visual problem-solving processes (e.g., time to first fixation). But for other visual processes (e.g., number of transitions, fixation duration on AOIs) these theories seem to be too limited. More insight in the origin of visual problem-solving processes is required and cognitive theories should be integrated with visual cognitive (i.e., perceptual) theories to explain all of our findings. For example, they should include the visual integration of information elements in order to explain findings on transitions. With regard to the investment of mental effort, especially the high effort reported by intermediates, such theories should also be able to distinguish more clearly between the working-forward strategies of experts and the strategies of intermediates, which seem to be somewhere between working forward and means-end analysis. Finally, for experts, an explanation is required for their ability to oversee all small but relevant details in visual stimuli and how their strategy to chunk and reduce incoming information elements enables this.

With regard to practical implications, our findings inform the design of eye-movement modeling examples (EMMEs) that can be used to train visual problem-solving strategies for novices, intermediates and experts. Novices use means-end analysis, do not yet have the ability to ignore irrelevant information, and possess no chunks to treat related information elements as one element when solving visual problems. Hence, EMMEs for novices should first show which information is needed to work forward to the goal instead of backward from the goal. That way, the learner is shown how decisions are made without taking the general destination point into account. Second, they must indicate which information is relevant for problem-solving, and where this information is located in the complex visual representation. Third, they should make visible which related information elements can be treated as chunks. And finally, they should reflect the divergence in visual problem-solving strategies applied by experts (Van Merrienboer & Kirschner, 2013) because the similarity of expert strategies is yet relatively high but might still lead to slightly different solutions.

For intermediates, EMMEs should primarily take into account their tendency to focus on irrelevant information resulting in a relatively high cognitive load. They should help them to reduce visual search by focusing on the information that is minimally required to take safe decisions. For example, EMMEs can be based on prototypical situations for which it is known that visual problem-solving profits from the use of a chunking strategy (e.g., Gobet & Simon, 1998). Then, intermediates learn how to recognize the most relevant information from a related group of objects and, next, why the grouped elements are crucial to rely on in a certain situation (i.e., chunking).

For experts, EMMEs can be used to train them in working with newly introduced technologies or regulations, which might require the observation of new information elements during visual problem-solving (e.g., additional information in aircraft labels from new spacing tools). In such situations, EMMEs can be helpful in the same way as they are for intermediates. Furthermore, EMMEs based on the eye-movements of peers or on own eye-movements can help to foster reflection on the use of own visual problem-solving strategies and so contribute to a process of deliberate practice (Ericsson, 2004).

A limitation of our study is that solely eye-tracking measures were used to reveal visual problem-solving strategies. A triangulation of data including – in addition to eye-tracking measures – self-reports (e.g., cued retrospective reports) and/or questionnaires could further disclose the use of visual problem-solving strategies and unravel their relation to, for example, knowledge structures and motivation. Furthermore, the number of participants in our study was relatively low because there are not many experts in ATC available, participation of these experts is expensive, and eye-tracking data require much time and effort to analyze. Although the number of participants per condition in our study is comparable to that of similar expertise research (cf. Gegenfurtner et al., 2011), results could have been more pronounced with more participants.

Concluding, this study gave insight in three developmental phases of visual problem-solving strategies across a range of task difficulties. It showed that strategies are clearly different for different levels of expertise and lead to more similar solutions as expertise increases. The findings provide important implications for the design of EMMEs for training in complex visual domains.

Our study showed that care must be taken in selecting eye-movement models in order to fit the development level of learners' cognitive schemas and their related visual problem-solving strategies.

CHAPTER 3

Cognitions of Successful Training in Air Traffic Control:
How Instructional Designers, Trainees, and Coaches Differ

The domain of air traffic control (ATC) requires professionals who can manage air traffic in a safe, efficient, and environmentally aware way. In addition, they must be able to anticipate and adapt to changes in their work environment (e.g., stricter environmental rules, new technologies) and be aware of how this affects their own future professional work and training needs. To be successful, thus, air traffic controllers must be able to direct their own learning by regulating their performance and identifying learning opportunities for maintaining their expertise. In this study, characteristics of successful learning in ATC training were examined. Focus group meetings with three groups - ATC training-designers, ATC trainers/coaches, and ATC trainees - revealed important regulation skills needed for successful learning. Differences and similarities between the groups are examined and discussed in light of a new ATC training environment.

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Continuously changing technologies require professionals who can learn throughout their careers to keep up with these changes. Professionals in air traffic control (ATC), for example, work in a highly dynamic environment (i.e., many complex changes in real time) requiring unerring human action. As domain, ATC is also dynamic in that it makes use of constantly changing tools, technologies, norms, laws, governmental policies, and so forth. This means that air traffic controllers are professionals who must possess the complex cognitive skills to systematically maintain their own expertise throughout their careers (i.e., lifelong learning), ATC *trainees*, thus, are future professionals who must acquire such skills for lifelong learning.

Current training in ATC is based on personal coaching where the coach rather than the trainee decides what should be learned and in what order. To make the shift to more learner-directed education, and thus allowing the trainees to gain the necessary lifelong learning skills, learners need to be involved in their own learning process (Boekaerts & Cascallar, 2006). Central to the research reported here is (1) how to help trainees develop self-directed lifelong learning skills (e.g., Van Merriënboer, Kirschner, Paas, Sloep, & Caniëls, 2009) and (2) which trainee characteristics contribute to successful self-directed learning.

Research has shown that it is important that different stakeholders in training, such as teachers and trainees, agree on the characteristics that foster success in learning (Kirschner, Carr, Van Merriënboer, & Sloep, 2002). When stakeholders do not agree on what should be learned and/or how it should be learned this can negatively influence learning because, ultimately, it is not what teachers do that affects learning but how it is perceived by their trainees (Könings, Van Zundert, Brand-Gruwel, & Van Merriënboer, 2007) or as Rothkopf (1970, p.325) famously stated, “You can lead a horse to water, but the only water that gets into his stomach is what he drinks”. In addition to teachers and trainees, educational designers are also important stakeholders (e.g., Kirschner et al., 2002; Könings, Brand-Gruwel, & Van Merriënboer, 2005). In the initial training for air traffic controllers, the stakeholders are the trainers/coaches, the trainees, and the training designers. To understand how training is designed and perceived, this research studies how the cognitions of these three groups differ with respect to determining and ranking the most important characteristics of successful learning in ATC, and in their rationales for ranking particular characteristics as either low or high in importance.

Characteristics of Successful Learning

Successful learners typically seem to employ a number of cognitive and meta-cognitive processes when they are successful (see Azevedo, 2009, for an overview). These processes - self-regulated learning (SRL) and self-directed learning (SDL) - enable and are essential to learning (e.g., Pintrich, 2000; Pintrich & De Groot, 1990; Pintrich & Zusho, 2002; Zimmerman, 2000, 2002). Zimmerman (1986; 1990) classified SRL strategies into five temporally related, non-hierarchical phases (e.g. Butler & Winne, 1995; Schunck, 2005), namely:

1. *Orientation* on the task to activate prior knowledge, which is known to foster the structuring of new knowledge (e.g., Mayer, 1979).
2. *Planning* performance before starting the task to set task-related strategies in terms of the learner's own learning goals (Zimmerman, 2008).
3. *Monitoring* task performance while performing the task to control the task performance process; that is whether performance leads to the set learning goals (Azevedo, 2005).
4. *Adjusting* task performance by adapting and regulating cognition, behavior, motivation, and context to reach the goals (Azevedo, 2005; Schunk, 2005).
5. *Evaluating* task performance to identify one's weaknesses and strengths (Boud, 1995; Eva & Regher, 2005).

SDL is broader than SRL in that it includes the assumption that learners have a role in selecting those learning tasks that fit their learning needs (Loyens, Magda, & Rikers, 2008). The concept of SDL originated in adult education and workplace learning, and plays an important role in on-demand education where learners select learning tasks and so shape their own learning trajectories. Supporting the development of SDL skills has been shown to have positive learning effects in secondary vocational education (Kicken, Brand-Gruwel, Van Merriënboer, & Slot, 2009b). In addition to what self-regulated learners can do, self-directed learners can also:

1. *Identify learning needs*. This requires the correct estimation of one's actual and expected levels of competence. This identification must be correct because otherwise learners will have a biased and subjective perception of their learning (Tousignant & DesMarchais, 2002).
2. *Set learning goals*. Based on the perception of one's own learning, learners can set realistic goals they want to achieve at the final attainment level.
3. *Identify human and material resources* that support learning. Material resources can include learning tasks of certain complexity levels with suitable levels of human guidance or support (Knowles, 1975; Van Merriënboer & Sluijsmans, 2009).

Figure 3.1 depicts these two concepts with SDL on the left and SRL on the right.

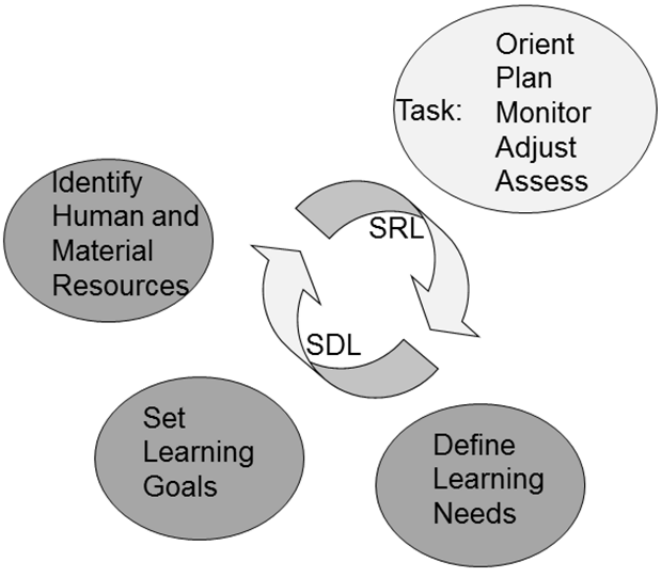


Figure 3.1 *Relation between self-regulated learning skills and self-directed learning skills.*

Positive learning effects have been reported for learners who consciously go through the iterative process illustrated in Figure 3.1 as opposed to learners who do not, especially in complex domains such as medicine (Boekaerts, 1999; Boekaerts & Cascallar, 2006; Eva & Regehr, 2007, 2008). Butler and Winne

(1995) attribute this to the fact that self-regulated learners are more aware of the quality of their knowledge, beliefs, motivation and cognitive processes than non-self-regulated learners. An example of this can be seen in the work of Kicken et al. (2009b), where learners in vocational education achieved better learning results when prompted to use the skills in Figure 3.1 than learners who were not. Kostons, Van Gog, and Paas (2010) found that in a setting where learners controlled their own learning trajectories, those who better assessed their own learning chose new learning tasks that better suited their learning needs. However, monitoring one's own performance and reflecting on it is difficult (Kostons, Van Gog, & Paas, 2009) and there is no learning gain when these skills are not adequately trained (Salden, Paas, & Van Merriënboer, 2006). Based upon this, it is expected that the development of SRL and SDL skills is needed for successful learning in ATC.

Two factors have been found to mediate SRL and SDL and thus indirectly support learning, namely learner engagement and self-efficacy. Pintrich and De Groot (1990) found that *learner engagement* mediates the learners' SRL process. This is in line with Zimmerman (1986, 1989) who noted that: "[S]tudents can be described as self-regulated to the degree that they are meta-cognitively, motivationally, and behaviorally *active participants* in their own learning process" (p. 329). This implies that active engagement supports SRL processes. Zimmerman also mentions motivation as an important mediator. More specifically, it is the belief that being capable of carrying out a task positively influences SDL. Schunk (1985) calls this belief *self-efficacy.* Pintrich and De Groot (1990) found positive relations between the learners' self-efficacy, self-regulation, and performance. This implies that both learner engagement and self-efficacy should be taken into account as mediators of SRL and SDL, and thus as possible characteristics of successful learning in ATC.

Different stakeholders

As stated, there are three stakeholders in ATC training (i.e., trainees, trainers/coaches, designers) who may see successful learning and its characteristics differently (Elen & Lowyck, 1998, 1999; Könings, et al., 2005), though education and training usually does not involve learners/trainees in the design process (Cook-Sather, 2001). This lack of involvement could lead to either an overestimation or, more likely, an underestimation by trainers/coaches and designers of the SRL and SDL skills that the trainees actually possess. This study examines the cognitions of the three groups as to the most important characteristics of successful learning in ATC training.

Research Questions

This study aims to answer three questions, namely:

1. According to stakeholders, which learner characteristics determine successful learning in ATC?
2. What are the similarities and differences between the three groups of stakeholders with respect to the importance of the learner characteristics?
3. What are the similarities and differences between the three groups of stakeholders with respect to their rationales for ranking particular characteristics as important or not?

Method

Participants

Twenty participants from the Dutch ATC training volunteered for this study. As focus group studies show that groups of 6-9 participants yield reliable information (Morgan, 1996), the participants were divided into three groups: *designer group* (*n* = 6; 6 female; mean age = 34.67 years, *SD* = 6.06), *trainer/coach group* (*n* = 7; 5 male, 2 female; mean age = 39.00 years, *SD* = 0.05), and *trainee group* (*n* = 7; 5 male, 2 female; mean age = 24.71 years, *SD* = 1.50). The designer group was composed of expert designers with at least one year of experience in the design of ATC training. The trainer/coach group consisted of coaches who work daily in the training program. The trainee group consisted of trainees who had completed 1 year of their initial 4-year training.

Materials

Focus group preparation task. Prior to the focus group meeting, participants were asked to complete a task based on the *critical incident method* (Flanagan, 1954) as input for structuring the meetings and to avoid possible dominance of one single participant in the group. The task consisted of three parts. First, the *designer* and *trainer/coach* groups were asked to think of a very successful trainee and write down what characterizes her/his learning. Then they were asked to think of an unsuccessful trainee and write down what characterizes her/his learning. Finally, they were asked to think of both trainees and write down the differences in how a successful and weak trainee approach and carry out ATC tasks. For the *trainee* group, the same approach was used with the trainee's own learning as starting point. First, trainees were asked to think of a typical training situation and write down how they would normally approach it. Then, they had to write down the differences between their approach and the approach used by others and elaborate on the characteristics of a successful trainee in such a setting. Finally, they were asked to think of a situation in which they had a successful learning experience and write down their own characteristics and the characteristics of others in this successful learning experience.

Focus group interview. The interview was used to identify characteristics of successful learning in ATC. The outcome of the preparation tasks was used to structure the interview whereby - per focus group - the list of characteristics of successful and unsuccessful learning was presented. One by one, all characteristics (first positive, then negative) from both lists were presented and discussed. The participants were asked to elaborate on each characteristic. Comparable with studies in usability research (e.g., Turner, Lewis, & Nielsen, 2006), three sources of information were expected to be sufficient to yield complete and relevant data. No new information was expected from adding extra focus groups.

Characteristics coding scheme. The importance of each characteristic, according to each focus group, was determined with the aid of a coding scheme developed in several iterations using the transcribed interviews as input. The scheme consisted of SDL and SRL skills (i.e., set learning goals, define learning needs, identify human and material resources, orient on task performance, plan task performance, monitor task performance, adjust task performance, and self-assess task performance) and other trainee characteristics related to learner engagement and self-efficacy (i.e., taking initiative, responsibility, reliability, control of emotions, coachability, independence, creativity in learning, intrinsic motivation, self-efficacy, and ATC talent) which are known to foster learning (Knowles, 1975; Zimmerman, 1986, 1989, 1990; Pintrich & De Groot, 1990). In total 18 exclusive characteristics were distinguished (Table 3.1).

***Table 3.1** Characteristics Coding Form*

Characteristic	Group	Explanation
Setting learning goals	SDL	Setting realistic learning goals to work on in future learning tasks and which fit reasonable learning.
Identifying human and material resources	SDL	Delineate a learning trajectory with the right materials and support from the right people for optimal learning.
Self-efficacy	SE	A proper estimation of one's own ability for performing an upcoming task.
Adjustment of task performance	SRL	The decision to change the strategy for solving a learning task when an unexpected outcome within a task occurs.
Coachability	SE	The willingness of the trainee to accept the coach's feedback and instructions which means a positive and open attitude of trainees towards their coaches' input.
Orientation on task performance	SRL	The preparation prior to the learning task start; considers learning needs before the task performance including the ability to estimate the learning goals which can be worked on in the task.
Self-assessment of task performance	SRL	The trainees' ability to assess task performance reasonably based on own perception eventually combined with support from others.
Intrinsic motivation	SE	The eagerness to learn and the intrinsic drive to achieve the set goals.
Control of emotions	SE	The ability to keep emotions in check, if not it could easily hamper learning.
Responsibility	SE	The attitude to not unload the responsibility for learning onto someone else.
Taking initiative	E	The attitude to actively take part in the learning process and the active attitude towards organizational aspects of learning.
Monitoring task performance	SRL	Following the task performance and notice difficulties or sub-optimal learning during this task performance.
Planning task performance	SRL	Elaborate on the possibilities of the task to plan an optimal individual learning task in it. So planning task performance taking individual learning goals into consideration.
Defining learning needs	SDL	Elaborate on earlier assessments and elusive the weaknesses in personal competences to work on.
Creativity in learning	E	Improvisation to optimize learning in a given situation in the task performance or in the learning trajectory.
Reliability	E	The attitude to be fair about ones performance and effort.
ATC talent	E	The talent of the trainee as the basic for successful learning.
Trainee Independence	E	The attitude in which the trainee is able to learn in an autonomous way without waiting for any direct support of coaches or peers.

SDL = Group of self-directed learning skills, SRL = Group of self-regulated learning skills, SE = Group of self-efficacy characteristics, E = Group of learner engagement characteristics.

Procedure

Participants carried out the focus group preparation task 1 week prior to the interviews. The results of the preparation tasks were given to the interviewer 1 day before the focus group meetings. All meetings were chaired by the same person who gave a general introduction to the topic and explained the discussion rules. Each meeting lasted approximately 2 hours and all meetings were audio-recorded and transcribed.

Data analyses

Transcription of the focus group interviews resulted in three protocols which were coded for the utterances about SDL, SRL, self-efficacy, and engagement. To train the coders, 15% of the protocols was coded by two researchers (i.e., the first two authors) using the Characteristic Coding Scheme. During this training, an inter-rater reliability (Cohen's Kappa) of .58 was achieved. After discussion of all statements for which they first disagreed, another 15% of the protocols were coded by the same raters, resulting in an inter-rater reliability of .90. Again, in all cases of dissimilarity the raters - after discussion - achieved consensus. After this second training phase, the first author individually rated the remaining protocols.

Results

Ranking

The three focus groups yielded separate rankings of characteristics based on the percentage of utterances related to a characteristic in each interview. The top-5 characteristics for the *designer* and *trainer/coach* groups and, due to an equal importance of characteristics, the top-6 for the *trainee* group are given in Table 3.2 and highlighted in gray. In the trainee group, characteristics with rank 3 through 6 had equal frequencies and were given an average rank of 4.5.

A total of 141 utterances was coded in the *designer* group who valued trainee *self-efficacy* as most important for successful learning in ATC (16.3% of the coded utterances). Next, they valued *identifying human and material resources for learning* (9.9%), *setting own learning goals* (8.5%), *intrinsic motivation* (7.8%), and *coachability* (7.1%) as most important characteristics of successful learning in ATC.

***Table 3.2** Ranking of Characteristics*

	Training designers		Trainers / Coaches		Trainees		Total Rank	
	Rank	%	Rank	%	Rank	%	*M*	*SD*
Setting Learning Goals	3	8.5	2	12.5	4,5	9.3	3.2	1.3
Identifying human and material resources	2	9.9	3	11.0	4,5	9.3	3.2	1.3
Self-efficacy	1	16.3	1	19.1	8.5	6.2	3.5	4.3
Adjustment of task performance	6,5	6.4	7	6.6	1	13.4	4.8	3.3
Coachability	5	7.1	5	7.4	10	5.2	6.7	2.9
Orientation on task performance	6.5	6.4	12,5	2.2	2	12.4	7.0	5.3
Self-assessment of task performance	11.5	4.3	7	6.6	4,5	9.3	7.7	3.5
Intrinsic motivation	4	7.8	9	5.1	12	3.1	8.3	4.0
Control of emotions	8	5.7	10	4.4	8.5	6.2	8.8	1.0
Responsibility	9	5.0	4	8.1	15	1.0	9.3	5.5
Taking initiative	11.5	4.3	7	6.6	13.5	2.1	10.7	3.3
Monitoring task performance	11.5	4.3	14,5	1.5	7	7.2	11.0	3.8
Planning task performance	17.5	0.7	14,5	1.5	4,5	9.3	12.2	6.8
Defining learning needs	17.5	0.7	11	2.9	11	4.1	13.2	3.8
Creativity in learning	14	3.5	12,5	2.2	17	-.-	14.5	2.3
Reliability	15	2.8	17	0.7	13.5	2.1	15.2	1.8
ATC talent	11.5	4.3	17	0.7	17	-.-	15.2	3.2
Trainee independence	16	2.1	17	0.7	17	-.-	16.7	0.6

A total of 136 utterances were coded in the *trainer/coach* focus group, who also perceived trainee *self-efficacy* as most important (19.1% of the coded utterances), followed by *setting own learning goals* (12.5%), *identifying human and material resources for learning* (11.0%), *own responsibility for learning* (8.1%), and *coachability* (7.4%).

A total of 97 utterances was coded in the protocols of the *trainee* group who valued their ability to *adjust within tasks* as most important for successful learning (13.4% of the coded utterances). Next they valued *orientation on task performance* (12.4%), followed by *setting own learning goals*, *identifying human and material resources for learning*, *self-assessment of task performance, and planning task performance* (all 9.3% of all coded utterances).

Agreement among the rankings of the groups was analyzed with Kendall's coefficient of concordance (*W*), a non-parametric statistic to determine the dependence between rankings of any number of judges yielding a *W* between 0 (no concordance) and 1 (full concordance) and a significance measure (Kendall & Smith, 1939). This revealed a significant agreement between the three groups ($W = .67$, $p = .008$). The standard deviation of the average ranking (see Table 3.2) is calculated as an indication for the similarity and dissimilarity between the groups on the characteristics. In this average ranking, the top is led by *setting goals* (average ranking = 3.2) and *identifying human and material resources* (average ranking = 3.2) which share the first place in importance followed by *self-efficacy* (average ranking = 3.5).

Furthermore, Kendall's correlation coefficients (τ) were calculated to determine the correlations between the rankings of the three groups separately. The rankings of the designer group and the trainer/coach group correlated significantly: $\tau = .593$ ($p = .001$). However, the trainees showed no significant correlation in ranking with the other two groups. The larger the standard deviations between the rankings of the characteristics of successful learning, the more the cognitions of the three groups differ. Looking more closely at the rankings, the concordance in the ranking of *setting learning goals* and *identifying human and material resources* was high between the groups (both *SD*s = 1.3). All groups ranked these characteristics in the top-5 characteristics. *Self-efficacy* (*SD* = 4.3) and *coachability* (*SD* = 2.9) are the characteristics which designers and trainers/coaches rate in the top-5 while trainees ranked this in the 10th place. Conversely, *adjustment of task performance* (*SD* = 3.3), *orient on task performance* (*SD* = 5.3), *self-assessment of task performance* (*SD* = 3.5), and *planning task performance* (*SD* = 6.8) were rated in the trainees' top-6 while the designers and trainers/coaches give these characteristics a lower priority. Other characteristics where the rankings between the three groups diverged are *intrinsic motivation* (*SD* = 4.0) and *responsibility for learning* (*SD* = 5.5).

Qualitative Differences between Groups

To gain more insight in the nature of the characteristics from the categories SDL, SRL, self-efficacy and engagement, and to explain why these characteristics were or were not perceived as important for successful learning by a particular group, a qualitative description per characteristic is given in the following sections

Setting learning goals. The designer group repeatedly distinguished goals on two different levels: "*Goal-oriented, which can be on several levels; a micro level (i.e., in the task) and a macro level (e.g., becoming an air traffic controller)*". The trainer/coach group focuses on the need of goal-setting before performing a task: "*For me it is important that trainees know what their learning goals are. This can give an important focus for a briefing*". The trainee group also focuses on the task, but in addition emphasized that goals which are too detailed can be overwhelming: "*In my opinion, it's more important to focus on one main goal instead of overwhelming us with a bunch of aspects that can be improved*". Thus, the trainees emphasize focusing on one goal at a time, while the other groups emphasize focusing concurrently on several goals. Furthermore, trainers/coaches and trainees emphasized the importance of goal-setting on a micro or task level, while designers also mentioned the importance of goal-setting on a macro level.

Identifying human and material resources for learning. The three groups agreed on why the identification of human and/or material resources for learning is important for successful learning. A trainer/coach illustrated this by saying: "*…Good learners set to work with elements in tasks which are out of the direct training scope, but which they see as an interesting opportunity for learning*". A designer illustrated this with: "*…he is able to center more on the coach and this trainee uses his experience*". And a trainee indicated this by saying: *"In the example of meteorology, for me lectures are more important than reading the book*".

Self-efficacy. Self-efficacy is seen by designers and trainers/coaches as most important for successful learning. This can be seen in utterances from the designer group and the trainer/coach group, respectively: *"…an optimistic 'self-image' is essential"* and *"trainees with high self-confidence are those who perform best".* Trainees see this similarly and feel it important to be positive: *"After a disappointing week, on Monday you should tell yourself: I can do it."* Thus, for all groups it is important that trainees have a positive feeling about the expected performance on subsequent tasks.

Adjustment of task performance. For successful learning, trainers/coaches and designers focused on the macro level (i.e., the big picture) and thus emphasized adjustment of task strategies and learning from mistakes. An example from the designer group is: "*Trainees should not stick to a mistake for many weeks, they should just change their mind and go on*". Similarly, an example from the trainer/coach group was: ´*…when an earlier mistake keeps haunting the trainee, that's a bad learning quality*". Trainees, in contrast, focused more on the micro level (i.e., the single task) and making adjustments while performing ATC tasks: "*If I failed in a task with the use of one strategy, I just tried another strategy*".

Coachability. Designers and trainers/coaches mention coachability as important for successful learning because it indicates an open learner attitude towards the coach. They stated: "*To make sure that they learn from coaching, it's important to see results from my coaching in next task performance*" and "*It's important that they give the feeling to the coach that they are willing to understand what they tell them*". The trainees had their own perspective on coachability as an indicator for successful learning. They focused on their relationship with the coach and how to deal with disagreements, for example: "*…If there was something which I disagreed on, I'd oppose it, however, in a very decent way*".

Orientation on task performance. Orientation on task performance was mentioned by trainees as important for successful learning since it helps carry out the task ahead. They mentioned, for example: "*I make sure that I'm conscious of possible conflicts ahead*", and "*Most of the coaches go over the points of improvement together with the trainee right before the learning task starts*". Designers and trainers/coaches focus more on the importance of performance development over tasks than performance on the next task only: "*A trainee prepares an exercise, and focuses on something specific to learn from*" and "*…when you're self-critical and watch the exercise beforehand, you're a good trainee when you can see the connection to other exercises*".

Self-assessment of task performance. All three groups agree on the interpretation of this characteristic. An example from the trainee group is: "*…well, when I focus on one specific competence and performance improves, then I easily understand how performance is linked to that competence*". In the trainer/coach group, one participant said: "*…a trainee must be able to say: this went wrong, this was why and this is how I feel about it*", and an utterance from the designer group was: "*...a good trainee can make a realistic estimation* *of his or her own performance*". In addition, the groups also agreed on the need for seeking support to reach an accurate self-assessment.

Intrinsic motivation. All groups agreed on the reason why intrinsic motivation is important for learning and agreed on the need for an eagerness to learn. An example from the designer group is: "*sometimes one just would like to have a box of intrinsic motivation to feed to the trainees*". And from the trainers/coaches: "*…often, the good trainee is an eager learner*". Trainees' noted: "*…[to be successful] one needs an eagerness to do things…and an eagerness to learn*".

Control of emotions. Concerning the control of emotions, all groups agree that keeping your emotions under control helps to be more successful. An example from the designer group is: "*…to park ones own emotions helps, so they do not take the overhand*". In the trainer/coach group it was noted that: "*A good trainee does not start crying*". Also, the trainees confirmed that emotions can hamper learning but also said: "*I think that emotions can help to determine a limit; I've had enough for this moment*". These examples indicate the different functions of controlling emotions in successful learning.

Responsibility. Both trainers/coaches and designers stressed the importance of learner responsibility the same way. In the protocols of both groups utterances were found like: "*An important criterion for the trainees' responsibility is whether they are on time for their classes and training sessions. Late arrival hampers learning*". The only utterance in the trainee group coded as responsibility was focussing more on responsibility in learning: "*Although along with me, many others in class failed the exam, one should feel responsible for own performance in first place and not blame others*".

Taking initiative. The trainers/coaches, specifically, face problems with trainees with a passive attitude and they expect their trainees to take initiative for successful learning: "*Proactive trainees are willing to see their own role in their education and do not only wait for the coach's solution*". Designers and trainees agreed with the trainers/coaches that taking initiative is important for improving the dialogue between trainee and trainer/coach. An example from the trainee group is: "*The initiative of the trainee in evaluations can support coaches to come to a more sophisticated assessment*" while a designer said: "*…not wait like: Everything comes to me automatically, but they should take initiative by themselves*".

Monitoring task performance. For monitoring task performance, trainees focus more on monitoring their learning needs while performing a task, whereas the designers and trainers/coaches focus more on monitoring the advantages and disadvantages of the use of specific ATC strategies. For example the trainees said: "*One is active during the exercise, focusing on one specific point of attention for learning*". While a designer stated: "*Just try, and see what happens using different strategies…*". And the only utterance on this characteristic from the trainers/coaches is: "*…the process that trainees recognize their mistakes…and recognize the problem, they are halfway to completing the [learning] process*".

Planning task performance. A noticeable difference between groups on this characteristic is that trainees focus on performing a task, while the other groups focus on planning the learning. An example from the trainee group is: "*One always should take time to plan first [before performing an exercise]*" The designer group mentioned: "*Planning when having an exam, for example, when you have to do everything at the very last moment…*" and the trainers/coaches mentioned: "*…it is preferable when a trainee can notify the coach in advance when he or she is going to try out new strategies. This prevents discussions afterwards between the trainee and the coach*".

Defining learning needs. There is agreement on the role of the definition of learning needs in successful learning. Defining the learning needs helps to focus on the right learning goals. Trainees experienced that: "*…only when weaknesses were mentioned repeatedly, was this put as a point of interest for learning for subsequent tasks*". Whereas the trainers/coaches uttered that: "*In a debriefing, it is important to show what went well and what still needs attention, so: what went wrong, why and how can this be solved?*" The designers remarked in line: "*…one realizes competences still are developed insufficiently, otherwise one does not know what to work on*".

Creativity in learning. Designers and trainers/coaches agreed on the need for a creative attitude for successful learning to create an optimal training environment. Trainees did not mention something about creativity at all. An example utterance from the trainer/coach group is: "*a good trainee thinks: they solved it in this way, then I'll do it in a different way*". The designers said: "*Creativity is a domain specific competence too…and I think that creativity in* *learning is closely related to the domain specific competence: Hey, something new happens, well, how must I solve this?*"

Reliability. All groups stressed the need for trainees to be reliable and to have open communication. Furthermore, reliability is conditional for trainers/coaches to estimate the trainees' performances also based on the trainees' input. An example of unreliable behavior mentioned by the trainer/coach group was: "*The trainee overlooked a taxi conflict. To disguise his mistake, he invented an excuse and pretended to have judged the situation without taking any action*". The designers said in the same vein: "*A trainee who wants to gloss over mistakes has a bad learning attitude*". And the trainee group remarked: "*One should make a personal overview of problems which might influence learning task performance prior to the start of an exercise. It's a pity if this is omitted and the exercise turned out to be pointless*".

ATC talent. A "natural talent" for ATC is a remarkable characteristic for successful learning in ATC. Natural talent is not something one can expect from all learners but it makes clear that according to some participants learning attitude is not always directly related to learning outcome. The designer group gave the example: "*…some people just perform very well. They just know how to do it, they have it in their genes*". And an example from the trainer/coach group is: "*…good competence development without a specific learning attitude …Yes, well…that's just a natural ATC talent*". In the trainee group, no utterances about this characteristic occurred.

Trainee independence. The trainees' ability and need to be independent is a relative notion for successful learning. It is indicated that there is need for an optimum between trainee independence and the dependence of the trainee on the trainer/coach. For example the designer group mentioned: "*They are not self-taught, so they need a coach to explain…*" stressing that even a natural talent needs coaching to learn. On the other hand, a trainer/coach stated: "*… trainees should not become coach dependent*". The trainee group did not mention anything about this characteristic.

Discussion

Overview of the Results

This study investigated the characteristics of successful learning according to three stakeholder groups, each with a specific role in ATC education (i.e., ATC training designers, ATC trainers/coaches, and ATC trainees). Quantitative analyses yielded average rankings for characteristics of successful learning according to the stakeholders while the qualitative analyses shed light on why the characteristics for successful learning in ACT are considered important by the different stakeholders.

Two self-directed learning (SDL) skills were mentioned as primary characteristics of successful learning in ATC, namely the ability to *set learning goals* and the ability to *identify human and material resources for learning.* Also the trainees' degree of *self-efficacy* was seen as an important characteristic for successful learning. With respect to self-regulated learning (SRL), *adjustment of task performance* was indicated as important for successful learning. From *learner engagement* related characteristics the most important characteristic for successful learning was the learners' degree of *taking initiative.* These results justify the conclusion that SDL skills are important for successful learning in a highly dynamic domain as ATC, but that characteristics such as *self-efficacy*, *adjustment of task performance,* and *taking initiative* are also important.

While there was a high overall agreement between the stakeholder groups, as seen in the significant correlation between the three rankings, differences between the rankings were also found. The finding that the three groups have different cognitions about the importance of characteristics of optimal learning is in line with earlier findings by Elen and Lowyck (1998, 1999), who found that learners have their own robust conceptions about the relationship between instructional interventions and learning. The largest differences were found between the rankings of the trainees and the rankings of the two other groups. The rankings of the designer group and the trainer/coach group correlated significantly, but these rankings did not significantly correlate with the ranking of the trainee group. The main difference with respect to the ranking is that trainees generally focus on optimal performance on one particular learning task, while trainers/coaches and designers focus on performance development over a series of tasks. Five major differences in ranking between the trainees and the other two groups can be explained directly by this difference in focus as exemplified in the qualitative data. The first four (i.e., adjustment of task performance, orientation on task performance, self-assessment of task performance, planning task performance) are important for the trainee to optimize her/his own performance: the main aim of the trainee for every learning task. The fifth difference relates to *self-efficacy*. Trainees emphasize the need for *self-efficacy* for performance of a specific task, while designers and trainers/coaches relate this to a higher level, focusing on general learning performance and general self-image. A sixth relevant difference was found between the trainees and the other two groups in the ranking of the characteristic *coachability*. Designers and trainers/coaches see *coachability* as one of the top-5 characteristics while trainees ranked it in 10th place. In line with the qualitative results found for 'independence', one can conclude that *coachability* is a matter of finding an optimum. On the one hand, trainers/coaches must be able to provide input on the trainees' performance, but on the other hand, trainees should be free and be able to work independently.

These qualitative and quantitative results reveal that learners do not automatically think about their needs and goals while carrying out learning tasks. This is in line with earlier findings by Kicken, Brand-Gruwel, and Van Merriënboer (2008) who demonstrated the need to prompt learners to use SDL skills. Corbalan, Kester, and Van Merriënboer (2011) found that learners have trouble identifying the right human and material resources for learning and thus seem to focus more on *performing* the tasks than on *learning* from those tasks.

Guidelines for Instruction

The aim of this study was to gain insight in important characteristics of successful learning in ATC and to determine how different stakeholders perceive these characteristics. What the characteristics are and how they are perceived will affect the design of training environments for air traffic controllers. On the one hand, the most important characteristics must be supported and fostered in the training environment. On the other hand, it is important to bring the perceptions of all of the stakeholders in line with the training because dissonance in cognitions of learners, trainers/coaches and designers influences learning and study behavior negatively (Bartholomew, Parcel, Kok, & Gottlieb, 2001; Könings et al., 2005).

It is apparent from the findings presented here that there are relevant characteristics of successful learning in ATC training which should get more attention than they presently receive. Taking these characteristics into account in instructional design means that one must design an environment that triggers the development of SDL and SRL skills, self-efficacy and learner engagement. In practice, this means that learners must be given a certain degree of responsibility over the setting of their own learning goals and delineating their own learning trajectories by selecting their own learning tasks based upon SRL skills such as self-assessment (Kicken et al., 2008). This requires an adaptive system that can provide learners with the personalized learning tasks needed for optimal learning (Corbalan et al. 2011; Salden, Paas, Van der Pal, & Van Merrieënboer, 2006; Salden, Paas, & Van Merriënboer, 2006). In an adaptive training system, trainees and coaches share control over identifying human and material resources (i.e. selecting tasks with the proper amount of guidance) to help trainees focus on their personal learning goals and identify their own individual training needs (Corbalan, Kester, & Van Merriënboer, 2006; Corbalan, Van Merriënboer, & Kicken, 2010). Coaching trainees on how to determine their own learning trajectories can be achieved by scaffolding the task-selection advice given to them (Kicken et al., 2008; Jossberger, Brand-Gruwel, Boshuizen, & Van de Wiel, 2010). Such advice can, for example, be based on a development portfolio (Kicken et al., 2009b) which gathers assessment information on both ATC skills and SDL skills (Aukes, 2008; Driessen et al., 2003).

To avoid undesirable dissonance in cognitions between learners, trainers/coaches and designers, *participatory design* of the training environment may offer a solution. In such an approach, trainees participate in designing their own learning programs which helps trainees, trainers/coaches and designers achieve a similar understanding of the aim of each task in the training trajectory (Elen & Lowyck, 1998). Moreover, participatory design has been found to result in improved educational design and better learning (Könings et al., 2005, 2007).

To conclude, this study yielded valuable suggestions to reach a closer correspondence between the views of trainees, trainers/coaches, and designers on how to make learning in ATC more effective. Further research should focus on the design of instructional interventions aimed at the characteristics for successful learning identified. Preferably, these interventions are realized in an adaptive training system where trainees and coaches have a shared responsibility for successful learning.

CHAPTER 4

Self-directed Learning in Adaptive Training Systems:
A Plea for Shared Control

In the field of aviation, air traffic controllers must be able to adapt to and act upon continuing changes in a highly advanced technological work environment. The proposition in this chapter claims that explicit training of self-directed learning skills (i.e. the ability to: formulate one's own learning needs, set one's own learning goals, and identify those learning tasks that help achieve personal learning goals) is important for future professionals in aviation. In this chapter, an adaptive training system is presented in which the system and trainee share control over learning task selection which can help trainees to develop their self-directed learning skills.

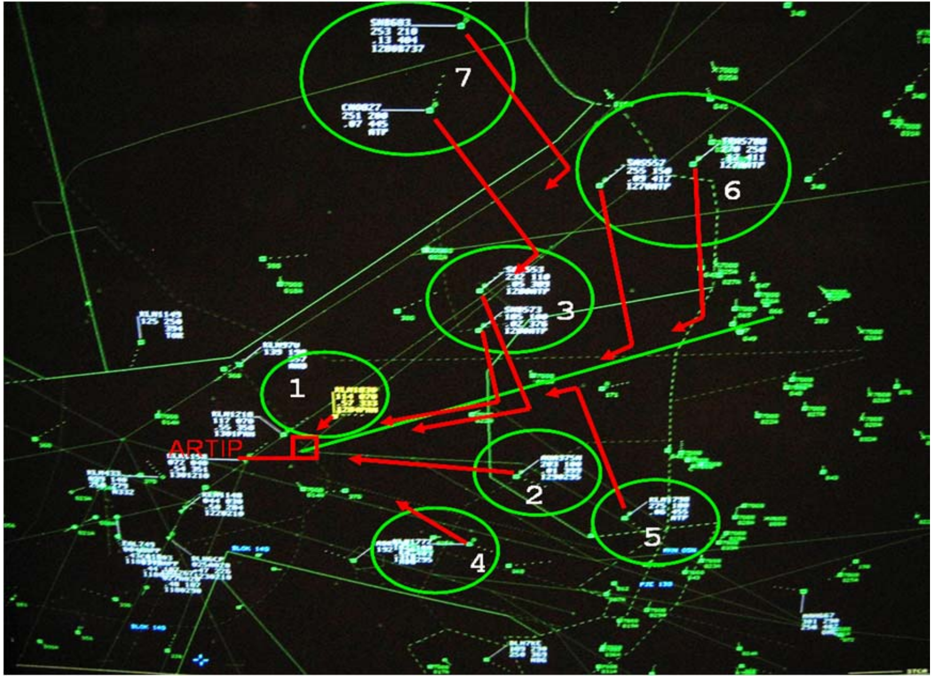
This chapter is based on: Van Meeuwen, L. W., Brand-Gruwel, S., Kirschner, P. A., De Bock, J. J. P. R., Oprins, E., & Van Merriënboer, J. J. G. (2013). Self-directed learning in adaptive training systems: A plea for shared control. *Technology, Instruction, Cognition and Learning.* Manuscript accepted for publication.

Air traffic control (ATC) is a complex cognitive skill because it requires coordination of many different skills, most of which are knowledge intensive and pertain to conscious decision making, and for which particular attitudes are critical to performing the skills in an acceptable manner (Van Merriënboer, 1997). The safety critical, dynamic and technology demanding nature of ATC further increases its complexity. First, life must never be at risk, which requires perfect human action within strict safety regulations. Second, all situations are dynamic because traffic in the air is always moving; this implies that not only decisions but also *omissions* of decisions will have either positive or negative outcomes (i.e., doing nothing is never an option). In addition, non-nominal situations due to unforeseen weather conditions, system failures, and incidents may greatly influence the dynamics of the ATC situation. Finally, the advanced technologies used help to create a safe and efficient flow of air traffic but also have their limitations because air traffic controllers must also be able to do their job in the face of failing technologies. Due to the complexity of the ATC domain, trainees are only accepted after a rigorous selection procedure.

The ATC domain is not only highly complex, but is also evolving at an increasing rate. Air traffic controllers are regularly confronted with major changes in the technologies they must use, and the working procedures and regulations they must follow. Therefore, they not only need to master domain specific ATC competencies (Oprins, Burggraaff, & Van Weerdenburg, 2006), but also need to be able to maintain their expertise and remain competent (Ericsson, Krampe, & Tesch-Romer, 1993), continue to learn (Norman, 1988), and direct their learning for optimal results (Eva & Regehr, 2005) throughout their career. In short, air traffic controllers should possess self-directed learning (SDL) skills to maintain expertise and they should be able to (1) formulate their own learning needs which specify discrepancies between their actual level of knowledge and performance and the desired knowledge and performance as specified in final attainment levels (typically imposed by an organization); (2) set learning goals which gradually steer their learning process towards the final attainment levels, and (3) select those learning tasks (e.g., tasks for practice, study of resources, asking for feedback) that best help them to reach their learning goals (Knowles, 1975; Van Merriënboer & Sluijsmans, 2009; Zimmerman, 2006). Figure 4.1 provides an example of a self-directed learner in the ATC domain who is studying in an adaptive learning environment. He can make decisions on the focus of his own learning.

Case Study: A Learner in an Adaptive Training System

Tom is trainee at an ATC provider for the unit radar control. He must learn to control civil air traffic from a radar screen. Tom functions well. He has the necessary skills to learn optimally in an adaptive training system: He is able to identify his own learning needs, set realistic goals, and identify new tasks that help to reach these goals.



Tom is currently training on-the-job and identified learning needs made him decide to focus his attention on the further development of workload management competencies. Workload management comprises the ability to adapt the working pace to the traffic load and the ability to keep calm, also during changes from light to heavy traffic.

The picture shows a radar screen with a given traffic situation. Tom should properly manage his workload to deal with this situation. All circles include one or two aircraft and all aircraft intend to land at the same airport. They should always be separated from each other by at least 5 nautical miles horizontally and/or 1000 feet vertically. In addition, before landing they should pass the initial approach fix called 'ARTIP' as efficiently as possible in one row, all at flight level 70 with a speed of 250 knots or less. The sooner Tom decides which aircraft to keep together and in which order chunks of aircraft pass ARTIP, the earlier he can adapt speeds, headings, and flight levels, leading to a lower workload. For example, Tom could early decide to use the indicated order (circles 1 to 7) and control the air traffic according to the given arrows. Then, fast action is required because the aircraft in circle 2 only needs 5 to 10 minutes to reach ARTIP from its current location.

Figure 4.1 *Case study part I.*

Many authors claim that SDL skills should be explicitly taught to learners in complex and quickly changing domains such as ATC (e.g., Bolhuis, 2003; Field, 2006; Kicken, Brand-Gruwel, & Van Merriënboer, 2008; Van Merriënboer & Sluijsmans, 2009). There is, however, little agreement on how to embed training of these skills in educational settings and how a training system should be designed to meet the demands of SDL. We argue that an adaptive training system is the solution where the system and the learner take control and where the system and the learner together are responsible for the learning trajectory of the learner. However, a major problem with traditional training systems is that they are mostly non-adaptive: All learners receive identical learning tasks and identical theoretical information. In such a static system, learners have no opportunity to learn direct their own learning; that is, they have no opportunity to acquire and practice SDL skills and receive useful feedback on their development of these skills. The main aim of the proposition in this chapter is to plead for adaptive training systems with shared control. In essence, such systems give learners the opportunity to formulate their own learning needs, set their own goals, and identify/choose their own learning tasks, but the responsibility for doing this is shared between the system (i.e., a human coach or other intelligent agents) and the learner so that interventions may help keep the learner on track and further develop both her/his domain-specific skills and SDL skills (Anderson, Corbett, Koedinger, & Pelletier, 1995; Corbalan, Van Merriënboer, & Kicken, 2010; Corbett, 2001; Jossberger, Brand-Gruwel, Boshuizen, & Van de Wiel, 2010; Winne, 2010).

The structure of this chapter is as follows. First, the concept of adaptive training systems is discussed in detail in the next section. A distinction is made between non-adaptive training systems and three types of adaptive systems with different levels of learner control. The subsequent section analyzes the SDL skills needed to optimally function in an adaptive training system with shared control and also describes regulative processes as a prerequisite for acquiring SDL skills. Then, the design of adaptive training systems with shared control is addressed, focusing on the three main elements of such a system: A database with learning tasks, a development portfolio, and a coaching protocol. The chapter ends with a general discussion of the presented framework and a description of future research lines.

Non-adaptive and Adaptive Training Systems

In non-adaptive training systems, all learners follow the same training program or sequence of learning tasks (i.e., one-size fits all). The program is typically based on the 'average learner' but, unfortunately, this average learner does not exist because each individual learner is more or less different from 'the average'. Corbalan, Kester and Van Merriënboer (2008) claim that the efficiency of non-adaptive training systems is low because they do not fit individual learning needs. For example, lower ability learners may work on a set of learning tasks that is too small (i.e., that does not contain enough tasks) for them to reach the final attainment level and thus drop out of the program, while higher ability learners work on the same set of learning tasks that is unnecessarily large for them to reach the final attainment level (i.e., that contains more tasks than they need) and lose their motivation. Adaptive training systems try to alleviate this by adapting the training program to the needs of individual learners by the selection of learning tasks which optimally suit the individual learning needs (i.e., adaptable personal learning programs). Each new task should explicitly focus on the learning needs to be fulfilled of the individual learner, meaning that the task is a bit too difficult for the learner but can nevertheless be completed thanks to instructional support and guidance (e.g. Vygotsky, 1978). This is believed to increase the efficiency of the training system because each learner follows a sequence of learning tasks adapted to his or her individual needs (Corbalan, Kester, & Van Merriënboer, 2006). In the next subsections is first described how different types of adaptive training systems especially focusing on the control over task selection (e.g., Scandura, 2007; Shute & Towle, 2003). Second, a comparison between these systems is made.

Types of Adaptive Training Systems

Depending on the level of control given to learners, three types of adaptive systems are distinguished: Adaptive systems with full system control over task selection, adaptive systems with full learner control over task selection, and adaptive systems with shared control over the selection of the learning tasks. Figure 4.2 provides an overview of these systems in comparison with a non-adaptive training system.

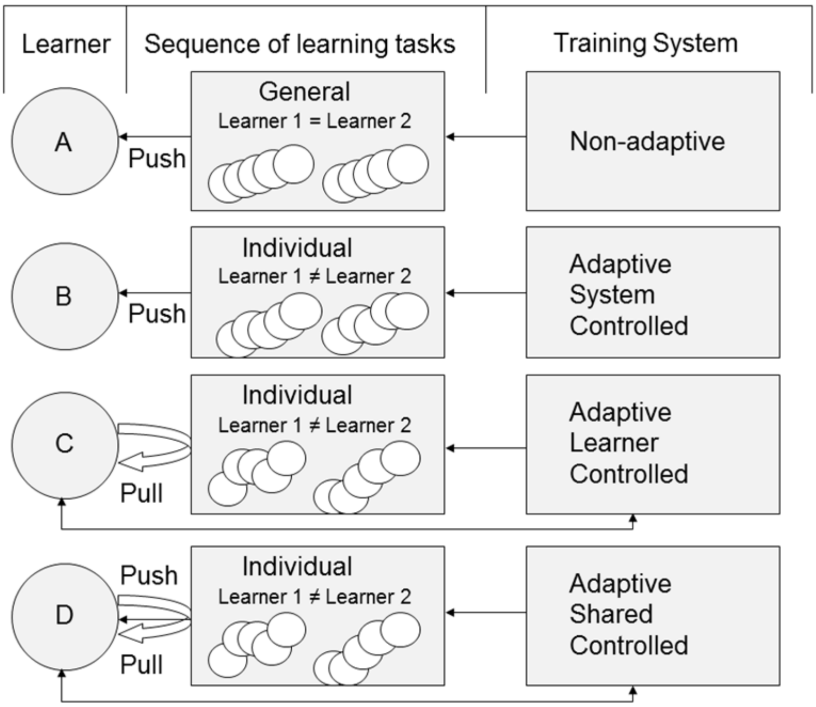


Figure 4.2 *Non-adaptive and adaptive training systems.*

In a non-adaptive training system (Row 1 in Figure 4.2), the same training program with exactly the same sequence of learning tasks is 'pushed' to all learners; learners have no opportunity to influence the instruction they receive. In an adaptive training system with full system control (Row 2 in Figure 4.2), each learner receives a unique sequence of learning tasks adapted to his or her individual learning needs. This sequence is determined by the system. To optimize the personal sequence of learning tasks, the system can have taken into account personal variables (e.g., former assessments). The system can be represented by a human coach or teacher, or the system can be represented by an intelligent agent replacing a human coach (e.g., computer program: Anderson et al., 1995; Scandura, 2007). However, this unique sequence of learning tasks is again 'pushed' to the learner, because s/he cannot influence the given instruction. This is in sharp contrast to an adaptive training system with full learner control (Row 3 in Figure 4.2), where each learner receives a unique sequence of learning tasks selected or adapted by the learner rather than by a coach or other intelligent agent. The learner selects tasks, based on former performances and assessments and taken into account the learning goals and the learning tasks are thus ‘pulled’ by the self-directed learner rather than ‘pushed’ by the system. Finally, an adaptive training system with shared control flexibly combines system control and learner control (Row 4 in Figure 4.2). In such a system, each learner receives a unique sequence of learning tasks that is sometimes determined by the learner (‘pull’) and sometimes by the system (‘push’) or is decided on in dialogue. For example, a coach or intelligent agent may make a pre-selection of suitable learning tasks, after which the learner makes a final task selection from this subset.

A Comparison of Different Training Systems

Different training systems can be compared on four requirements that are important for training in complex, fast-changing technological domains. Such a program: (a) must guarantee that learners either attain the final attainment level or are removed from the program, (2) must be as efficient as possible, that is, learners do not have to spend time or effort on unnecessary activities, (c) must provide learners with opportunities to develop SDL skills in addition to domain-specific skills, and (d) allows teachers or coaches to monitor individual learner progress on both domain-specific skills and SDL skills and provide specific guidance and feedback. Table 4.1 rates each of the four systems on the four requirements: A plus (+) or minus (–) sign indicates that the requirement is either met or not met, a question mark (?) indicates that the requirement can possibly be met depending on the design of the system and/or the functioning of the learner in this system.

With regard to *reaching the final training goals*, non-adaptive training systems will typically ensure that learners who pass the examinations will reach the final attainment level; learners who do not pass the examinations are removed from the program. The same is true for an adaptive training system with full system control. Such a system will continue to provide learning tasks to an individual learner until the final attainment level has been reached; learners who do not make sufficient progress are removed from the program on the fly or choose themselves to stop. The selection of the learning tasks by the system may, for example, be based on sub skills that have and have not been practiced yet, on previous task performance, on effort invested in performing the tasks, or on combinations of these factors (Salden, Paas, Broers, & Van Merriënboer, 2004; Scandura, Koedinger, Ohlsson, Mitrtovic, & Parquette, 2009; Shute & Towle, 2003). The situation is different in adaptive training systems with full learner control. There, learners might select suitable tasks that help close the gap between their current performance and goal performance (i.e., fulfill their learning needs), but may also select unsuitable or irrelevant tasks (Scandura et al. 2009), so there is no guarantee that final attainment levels are reached. This problem can be solved in a system with shared control. There, the system can limit the learner's choices of learning tasks in such a way that it ensures that either the final attainment level is reached or the learner is removed from the program when insufficient progress is made.

Table 4.1 *Rating of Non-adaptive and Adaptive Training Systems*

	Insurance Final Attainment Level	Training Efficiency	Developing SDL Skills	Progress Monitoring
Non-adaptive	+	-	-	?
Adaptive, System Control	+	+	-	+
Adaptive, Learner Control	-	?	?	?
Adaptive, Shared Control	+	+	+	+

With regard to *efficiency of training programs*, research in the ATC domain showed that non-adaptive training systems are relatively inefficient; that is, they yield lower learning outcomes or require more effort (e.g., a higher number of learning tasks, higher learner cognitive load) than adaptive systems with full system control. Camp, Paas, Rikers and Van Merriënboer (2001) and Salden, Paas and Van Merriënboer (2006) randomly assigned learners in the ATC domain to an adaptive condition where the selection of new learning tasks was based on individual learning needs and a non-adaptive condition where it was not. In both studies, learners in the adaptive condition achieved higher learning outcomes. Salden, et al. (2004) compared the effectiveness of a non-adaptive, easy-to-difficult sequence of learning tasks with an adaptive sequence based on a relative measure of mental efficiency (i.e., higher performance combined with lower workload: the higher the mental efficiency, the more difficult the next presented learning task). In this study, the adaptive sequence yielded more efficient transfer-test performance than the non-adaptive easy-to-difficult sequence. For an adaptive system with full learner control, the situation is less clear. In principle, learners with well-developed SDL skills can select suitable learning tasks that result in an efficient learning process, but research has shown that learners often select suboptimal tasks (Salden, Paas, Van der Pal, & Van Merriënboer, 2006). For example, Corbalan, Kester and Van Merriënboer (2011) found that learners selected tasks on the basis of their surface features rather than their structural features, with negative effects on the learning process. This problem can be solved in a system with shared control, where the system can annul suboptimal learner choices. For example, the system could stimulate or even force learners to base their task selections on structural rather than surface features.

With regard to the *opportunity to develop SDL skills*, a non-adaptive training system does not give learners the opportunity to develop these skills because learners cannot select their own learning tasks; there is no value whatsoever in formulating one’s own needs and setting one’s own goals. The same is true for an adaptive training system with full system control. Here, learners receive learning tasks based on their individual learning needs, but those needs and subsequent goals and learning tasks are fully determined by the system. The situation is completely different in an adaptive training system with full learner control where learners have the freedom to formulate their own learning needs, set their own goals, and select their own learning tasks – and thus practice their SDL skills, though SDL skill development is not explicitly supported. Especially for lower-ability learners, there is a clear risk that learners will choose suboptimal tasks with negative effects on the development of both domain-specific skills and SDL skills (Kicken et al., 2008). An adaptive system with shared control provides a solution to this problem because it offers support, guidance, and feedback on the development of SDL skills and guarantees that learners do not select counterproductive tasks. One powerful approach is to gradually give learners increased control over the selection of learning tasks as their SDL skills develop, smoothly shifting the selection responsibility from the system to the learner until a situation of full learner control is reached (Corbalan, Van Merriënboer et al. 2010; Jossberger et al., 2010). This approach proved to be effective in studies conducted by Kicken et al. (2008) and Corbalan et al. (2008). In the study by Kicken et al., the learners selected the learning tasks in dialogue with a coach, who gave them advice on the proper formulation of their learning needs, the setting of goals, and the selection of suitable tasks. Moreover, the coach gradually transferred the responsibility to the learners. In the study by Corbalan et al., a computer program made a pre-selection of suitable tasks from which the learner could make a final selection, and the size of the preselected subset increased as learners' SDL skills developed.

Finally, with regard to the *opportunity to monitor progress* of individual trainees, monitoring progress of domain-specific skills is basically possible in all of the training systems while monitoring progress of SDL skills is not. In a non-adaptive system, there is no incentive to monitor the development of domain-specific skills because all trainees receive identical instruction independent of the outcomes. Here, monitoring only has added value when its outcomes are used to provide additional remediation where necessary. Furthermore, monitoring SDL skills development is irrelevant because trainees have no opportunity to apply these skills. In an adaptive training system with full system control, monitoring the progress of domain-specific skills is a necessity because otherwise it is not possible to provide instruction tailored to individual needs (e.g., Scandura, 2007). Here too is the monitoring of SDL skills development irrelevant because trainees have no opportunity to apply them. In an adaptive training system with full learner control the situation is less clear. Again, there is no direct incentive for monitoring because trainees can select the tasks they want independent of the monitoring outcomes though, in order to help trainees develop their domain-specific skills and/or SDL skills, they may be given tools (e.g., scoring rubrics, portfolios, logbooks) that help them keep track of progress on domain-specific and/or SDL skills. Finally, in an adaptive training system with shared control, there is a clear need to monitor trainee progress on both domain-specific and SDL skills because otherwise it is not possible to intervene when trainees make suboptimal decisions.

To conclude, the analysis provided indicates that an adaptive system with shared control is the only system displaying the four desired characteristics for training learners who must develop the complex skills to work in fast changing technological environments in that it: (1) guarantees that learners who are suitable for the job reach the final attainment level, (2) yields efficient training, (3) provides the opportunity to develop SDL skills, and (4) offers good opportunities to monitor trainee progress on both domain-specific skills and SDL skills. Before describing the design of such an adaptive training system with shared control, a more detailed analysis of SDL skills is provided.

Self-directed Learning Skills

What is expected from learners who work in an adaptive training system with shared control? To answer this question, first, we return the Tom's case and study how SDL skills can be applied in practice in more detail and then we briefly discuss the intricate relationship between SDL skills and self-regulation skills. Figure 4.3 shows how Tom directs his own learning while he is supported in doing this by his coach.

With regard to the formulation of learning needs, the upper part of Figure 4.3 shows that Tom is able to identify these needs thanks to the assessment of problems or shortcomings in previous performance (in this case, problems with workload management). Three features of the assessment process contribute to the quality of formulated needs. First, the assessment of one's own performance is made in light of – a known or assumed – final attainment level which is often reflected in the behavior of experienced colleagues and/or in performance criteria and standards (Sluijsmans, Dochy, & Moerkerke, 1999). The availability of criteria and standards makes it easier to gain insight in one's own level of competencies (Anderson, 1990; William & Black, 1996). Second, assessments are not limited to performance on one particular task but also consider progress, or lack thereof, over a series of tasks (Kicken, Brand-Gruwel, Van Merriënboer, & Slot, 2009a). Third, other persons (e.g., coaches, peers) and resources (e.g., portfolios, written reports) are consulted to validate the assessments (Boud, 1995; Sergeant, Mann, Van der Vleuten, & Metsemaker, 2008). These three features help the learner formulate specific learning needs that provide a good basis for goal setting. If not, learners will be inclined to formulate general and vague needs (e.g., “I have to work faster” rather than “I need to decide more quickly on the specific order of aircraft”), which provide little footing for subsequent goal setting (Kicken et al., 2008).

Before Tom started training in the simulated environment, he was training on-the-job. Tom noticed in his development portfolio that he repeatedly scored low on the standards for workload management. Moreover, he observed he made too little progress on this particular competence compared to his peers; each time the traffic load changed from light to heavy traffic he became overloaded. He consulted his coach and together they studied the discretion of workload management thoroughly. In order to improve future performance, they decided to diagnose Tom’s shortcomings in the workload management competence.	Defining Learning Needs
Together they concluded that Tom first needed to further practice the skills of chunking and early decision making, and to automate the actions of label input to develop workload management competencies. Second, they realised that label input still was too demanding for him. The goal to improve workload management was subdivided in two smaller goals. First, improving the basic use of strategies (i.e., chunking and early decision making) to manage the transition from light to heavy traffic. And second, improving the label input skills.	Setting Learning Goals
Next Tom and his coach delineated a series of tasks which are suitable to reach the set learning goals. The desire for repeated practice and Tom’s wish to freely experiment with new workload management strategies asked for a safe training environment: the simulator. In the simulator, training situations can be paused during task performance so that the coach can give optimal support and guidance. Furthermore, tools for practicing label input become available that help Tom to fully automate his label input skills.	Identifying Learning Tasks

Figure 4.3 *Case study part II.*

With regard to setting learning goals, the middle part of Figure 4.3 shows that Tom - in dialogue with his coach - decides to set three specific goals (i.e., improve chunking of aircraft, make quicker decisions on aircraft order, automate the label input skill). In addition, prioritizing is an important aspect of goal setting because it is not effective to aim at too many goals at the same time because this causes cognitive overload and hampers learning (Van Merriënboer & Sweller, 2005). Therefore, it was decided to first work on those goals that will enable Tom to manage the transition from light to heavy traffic. The further automation of label input skills is set as a second goal to deal with.

Finally, with regard to the identification of suitable learning tasks, the bottom part of Figure 4.3 shows that Tom identifies - again in dialogue with his coach - the human and material resources needed to further train his workload management competencies. It results in the selection of a series of learning tasks in the simulator with a suitable level of complexity, difficulty, guidance, and support. Moreover, Tom's personal preferences are taken into account (i.e., his wish to freely experiment with new strategies). In a second stage, Tom will use the simulator to further practice his label input skills (i.e., 'part-task practice') and the coach will be around to provide any necessary information, feedback, or advice.

After Tom experienced he had problems with workload management, he decided – in consultation with his coach – to further train his workload management competence using the simulator. He especially wants to practice dealing with changes from light to heavy traffic. Before Tom starts his first series of simulator tasks he specifies his learning goal and decides to experiment with recently learned strategies for improving workload management.	Orienting on task performance
He plans to apply strategies such as deciding on the order of aircraft more quickly, chunking aircraft, and labeling input. So Tom should decide earlier in which order the aircraft should pass ARTIP.	Planning task Performance
While Tom is performing his first learning tasks he experiences that his workload is still too high and he realizes that especially the uncertainty about the optimal aircraft order at ARTIP causes the problem. He decides that it may be helpful to focus even more on the chunking strategy.	Monitoring task Performance
He glances at his coach and asks him 'OK, should I focus on chunking now?' The coach nods. Tom continues and decides not to worry about a possibly wrong chosen order of aircraft, especially at demanding moments	Adjusting task Performance
After the task has been finished Tom evaluates both his task performance and learning process, using the assessment criteria for workload management and SDL skills. The coach also provides his evaluation, so that Tom can compare this with his own evaluation. Tom concludes that his own evaluation is largely in line with the evaluation of the coach, although they differ in their evaluation of adjustment of strategies. The coach argues that Tom hesitated too much when adjusting the strategy. In Toms' view he did not hesitate but only wanted approval of the coach to focus more on the chunking of aircraft.	Evaluating task performance

Figure 4.4 *Case study part III.*

From the description of the aforementioned SDL skills, it becomes clear that SDL skills have a complex relationship with self-regulation; the ability to regulate one's own cognitive and learning processes. When learners formulate learning needs, they must be able to evaluate their own cognitions to find out what they know and, possibly more important, what they do not know (Eva &

Regehr, 2007, 2008). When learners set learning goals, they must be able to estimate their own cognitive resources to simultaneously deal with multiple goals. And when learners select particular learning tasks, they must be aware of their own preferred learning styles. Figure 4.4 illustrates some of Tom's regulative processes while he is working on one particular learning task.

The figure shows that Tom's work on this learning task reflects self-regulation skills to adaptively change his strategies to the dynamic traffic load. The earlier a decision is made about the traffic order, the less extreme an aircraft needs to adapt speed and/or heading and the easier it will be for Tom to merge the aircraft in the group of other inbound aircraft. Chunking is an important strategy to diminish workload. If a separate cluster of aircraft with similar performance materializes on the radar heading for ARTIP, Tom should learn to keep this cluster together and form one chunk of aircraft rather than treating the separate aircraft as separate objects (cf. Figure 4.1, where Tom should keep the aircraft in cluster 6 in one line behind each other; an instruction to the first aircraft implies a similar instruction to the second one). Correct labeling of aircraft also decreases workload. The labels of the aircraft on the radar screen (see Figure 4.1) comprise not only the call signs (e.g., KLM 1770) but also flight information (e.g., assigned flight level). The air traffic controller has to insert the values of assigned heading, speed, and flight levels. The more Tom automates the sub process of labeling, the less workload it will take him to perform the whole task.

Self-regulation strategies can be classified according to Zimmerman's five phases (1986, 1990): (1) orientating on the task, (2) planning performance before starting the task, (3) monitoring task performance while performing the task, (4) adjusting task performance, and (5) evaluating task performance after the task has been finished. First, Tom orients himself on the task and works out which learning opportunities it offers (i.e., experimenting with strategies for workload management). Second, he plans which aspects to focus on during task performance (i.e., chunking, ordering, labeling). Third, during task execution, he monitors performance and tries to identify possible causes for shortcomings (e.g., too high workload due to too late ordering of aircraft). Fourth, Tom adjusts his behavior as a result of the monitoring; he focuses more on the chunking of aircraft and less on their chosen order. He also asks his coach if this a good strategy, which is a valuable action because feedback from the coach may help to improve self-regulation processes (Van den Boom, Paas, & Van Merriënboer, 2007). Fifth, after task completion, he evaluates his own behavior both with regard to performance and learning.

The self-regulation skills described are clearly conditional for developing SDL skills. One cannot formulate learning needs, set learning goals, or select learning tasks without being able to evaluate one's own task performance, orient oneself on new tasks, plan the focus of future learning processes, and so forth. Thus, self-regulation skills support SDL skills (Van den Boom, Paas, Van Merriënboer, & Van Gog, 2004). This is not to say that a training program for SDL skills should always include explicit training of self-regulation skills; it merely indicates that learners can only be successful in the development of SDL skills when they are sufficiently able to regulate their own learning. Along the same lines, learners can only be successful in developing ATC skills when they are able to read, but reading instruction will typically not be part of ATC training.

In conclusion, learners who work in a training system with shared control are in a good position to practice their SDL skills, assuming that they already possess basic skills for self-regulation. The training system should explicitly support the development of SDL skills through the provision of models, guidance, and feedback. The next section concerns the design of a training system with shared control, aimed at the development of SDL skills that help professionals maintain their expertise and continue their learning. The three main elements of such a system will be discussed, namely, a database with learning tasks, a development portfolio, and a coaching protocol.

The Design of an Adaptive Training System with Shared Control

Like domain-specific skills, SDL skills do not develop spontaneously but are trainable (Gordon, 2003; Winne, 2010). A well-designed training system must, thus, explicitly foster SDL skills development (Ericsson, 1998; Plant, Ericsson, Hill, & Asberg 2005; Winne, 1995; Winne & Perry, 2000). Most authors agree that guidance and support for acquiring SDL skills should not be isolated, but rather should be embedded in, or intertwined with, domain-specific training (e.g., Boekaerts & Cascallar, 2006; Brown, 1997; Cascallar & Boekaerts, 2006;

Jossberger et al., 2010; Ten Dam & Volman, 2004). In other words, the training system should be designed such that the training of SDL skills goes smoothly along with the training of ATC skills.

Kicken et al. (2008) describe an ‘informed self-directed learning model’ in which three components are distinguished to support the development of SDL skills: (1) a database with learning tasks, (2) a development portfolio, and last but not least (3) a coaching protocol. Figure 4.5 shows how these components are related to each other in a training system with shared control. Learners can select tasks from the learning task *database.* To allow for careful selection, metadata for each task provide information on goals that practicing the task can reach, task difficulty, available support and guidance, and so forth. The *development portfolio* keeps track of all performed tasks and monitors the development of competencies on a given set of criteria and standards. Finally, in ATC training the aim is not to replace the coach by an intelligent agent (e.g. Anderson et al., 1995; Scandura, 2007). Therefore the *coaching protocol* prescribes how the coach in person should support and guide the learners with the identification of learning needs, the setting of learning goals, and the selection of new tasks.

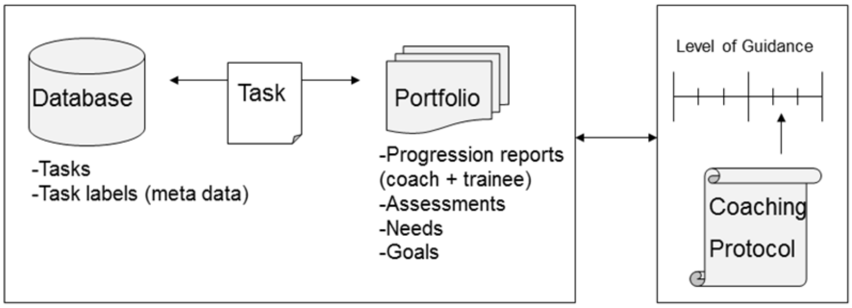


Figure 4.5 *Elements of an adaptive training system with shared control.*

The self-directed learning model supports a cyclical learning process. The learner selects one or more learning tasks from the task database (Figure 4.5), carries out the task/tasks, gathers assessments of the task/tasks in the portfolio, selects one or more new learning tasks from the database taking the information in the portfolio into account, and so on. Each cycle, the updated information in the portfolio is used to formulate/reformulate individual learning needs and set new learning goals in order to select suitable tasks. The coach or a computer system uses the coaching protocol to support and guide the whole process of formulating learning needs, setting learning goals, and selecting new tasks and so optimizes the development of both domain-specific ATC skills and SDL skills. The next sections describe the three components and the cyclical learning process in more detail.

Database with Learning Tasks

The database contains learning tasks that enable learners to develop required domain-specific competencies in an authentic setting. This implies that learning takes place in a realistic environment, either the work setting itself or a simulation thereof. Ideally, learning tasks make use of a rich set of ATC competencies and authentic, 'whole' tasks for the integration of knowledge, skills, and attitudes (Van Merriënboer & Kirschner, 2013).

The metadata that should be minimally available for each task in the database, so that a suitable task can be selected, are the learning goal/goals to be reached by practicing the task, the context in which the task is performed, the difficulty level of the task, and the available amount and form of support and guidance (Kicken et al., 2008). Each individual task in the database has one or more learning goals related to it, providing insight in the skills or competencies that can be acquired by practicing the task. The context concerns the situation or setting in which the task needs to be performed. For example, the same task can be performed at Amsterdam Schiphol airport or London Heathrow airport (or a simulation thereof). The difficulty level of the learning task concerns, for example, the number of elements that must be dealt with and the degree of interaction between those elements. ATC learning tasks for practicing workload management may differ in the number of aircraft to be handled and the interactions between their take-off and landing trajectories and/or speeds in a specific time slot and under specific weather conditions. Finally, the level of support and guidance available during task performance can differ. A learning task that is combined with a worked-out example or with a process worksheet that guides the learner through the process has a fairly high level of support. In contrast, an on-the-job task that must independently be performed by the learner provides no support or guidance at all. An optimal selection of learning tasks should ensure that learners work on tasks that help them reach their individual learning goals, show variability in contexts, are at the right level of difficulty, and provide the necessary amount of support and guidance. Moreover, as the learner expertise increases, the task difficulty should also increase and the amount of support and guidance given should gradually decrease in a process of 'scaffolding' (Van Merriënboer & Kirschner, 2013).

In an adaptive training system with shared control, the learner can select suitable learning tasks from the database in consultation with the coach or system. The selected tasks should fit the individual goals of the learner, and also properly support the competency development process by offering a variety of contexts, being at the right level of difficulty, and providing the necessary support and guidance. The database stores the learning tasks as learning objects with information about goals, contexts, difficulties, and supports as metadata. The learner and the coach can search the database for appropriate learning tasks by using the required metadata in a search query.

Development Portfolio

A development portfolio keeps track of performed tasks and gathers assessment information for these tasks. An *electronic* portfolio has the advantage that it can take over administrative duties and conduct computational tasks to generate overviews and summaries (Kicken et al., 2008; Kicken, et al. 2009a). In principle, all performed learning tasks might be used as a basis for assessment and be included in the portfolio. Typically, 'scoring rubrics' allow an assessor to assess the learner's performance on each learning task. The assessor can select relevant aspects of performance; for example, from a hierarchical list with more global aspects of performance at the top and more detailed aspects of performance lower in the hierarchy. For each aspect, the portfolio shows the criteria and standards for acceptable performance and the associated scoring rubric, allowing the assessor to rate the aspect of performance under consideration. This process is repeated for all aspects relevant for the learning task assessed, and if more than one task is assessed, it is repeated for all tasks. To improve the informative value of the portfolio, scoring rubrics need not be limited to quantitative ratings of particular aspects of performance, but may also include narrative information which might be given by the assessor in a separate textbox, as well as other indicators of competence development such as progress reports, examinations, and so forth. The same development portfolio should be used throughout the whole training program. An advantage of this approach is that the learner is confronted with all relevant standards from the start of the program. Although the learner will not be assessed on all standards immediately, the final attainments levels are communicated from the start and so help the learner to work towards them. Basically, the portfolio, thus, provides information about the performed tasks, the current state of the learners' competencies, and the development of those competencies over learning tasks.

Ideally, a multitude of assessors should be responsible for updating the portfolio, including teachers, coaches, peers, and so forth. Obviously, the learner will also use the portfolio to conduct self-assessments; in a training system with shared control, such self-assessments are critical to the development of SDL skills. In addition, a mix of assessment methods should be used to collect the data that are entered in the portfolio, because all assessment methods have their own advantages and disadvantages. For example, assessment methods with a high reliability typically have a relatively low external validity and, vice versa (Van Merriënboer & Sluijsmans, 2009). Possible conflicts between assessments made by different assessment methods and/or by different assessors (including self-assessments) can be automatically detected by an electronic portfolio and used as input for discussion in coaching sessions.

How does a development portfolio support the development of SDL skills? First, the assessments gathered in the portfolio and the information they provide on competency development offer a good basis for identifying individual learning needs. Discrepancies between different assessors, including the learner herself/himself, may help the learner gain a clearer impression of those needs. Second, the learning needs may be related to the criteria and standards as specified in the portfolio to formulate points of improvement and set new learning goals. And third, the learning goals may be related to a database's metadata with learning tasks to select new tasks and plan the individual learning trajectory. A self-directed learner will be able to use the portfolio to identify her/his needs, set goals, and select tasks. In a training setting, explicit instruction and/or coaching sessions should be organized to support and guide the learner in developing SDL skills. The overviews and summaries generated by the portfolio also provide helpful information for such meetings with a coach. Moreover, a coaching protocol may help the coach or a computer system to provide the necessary support and guidance for the development of SDL skills.

Coaching Protocol

A training system with shared control should make learners increasingly responsible for the self-directed learning process (Kicken et al., 2008). The coaching protocol provides instructional strategies for the integrated teaching of domain-specific skills and SDL skills. The strategies can be applied by either a human coach or a computerized system, which may be part of an electronic development portfolio. Ideally, the strategies specified in the coaching protocol help the learner identify learning needs, set new goals, and select future learning tasks.

A first set of strategies should help the learner translate assessments and self-assessments, which may be gathered in the portfolio, to learning needs. This is a difficult process, because the learner is often aware of imperfections in performance but not of the underlying causes of these imperfections, making it difficult to specify concrete learning needs. A promising strategy to help learners identify learning needs is ‘cued retrospective reporting’ (Van Gog, Paas, Van Merriënboer, & Witte, 2005) where all actions of the learner and their results (e.g., changes on the radar screen) are recorded and one or more recently performed learning tasks are ‘played back’ so that the learner may be guided in a systematic process of reflection. A coach can help the learner interpret previous performance, identify possible causes of shortcomings in performance, and so identify learning needs.

A second set of strategies should help the learner set new learning goals. For example, the learner and a coach can collaboratively define new learning goals in a ‘reflective dialogue’ (Kicken, Brand-Gruwel, Van Merriënboer, & Slot, 2009b, 2012). By asking reflective questions such as “Do you think you can simultaneously work on these three goals?” or “How long do you expect it to take you to reach this goal?” the coach can successfully help the learner to formulate more realistic goals and more concrete points of improvement. Moreover, reflective dialogue not only helps the learner define more realistic goals but also gives the coach better insight in the learner’s level of SDL skills.

Reflective dialogue could, in the same way, be used to train and assess the identification of learning needs and the selection of future learning tasks.

A third set of strategies provides the learner, in comparison to reflective dialogue, with more direct advice on the selection of future learning tasks. As discussed in the section on different training systems, research on training systems with full system control developed successful algorithms for selecting learning tasks. Such algorithms may also be used as a starting point for giving learners advice on the selection of future learning tasks. Previous research in the biology (Corbalan et al., 2008; Corbalan, Kester, & Van Merriënboer, 2009a) and ATC (Salden et al., 2004) showed that combining algorithms and human intervention (i.e., the coach or the learner) is superior to full system control. Van Merriënboer and Sluijsmans (2009), for example, specify the following heuristics to give learners advice on task selection: If you are able to perform supported learning tasks up to the standards, select future learning tasks with less support and guidance than previous tasks; if you are not yet able to perform supported learning tasks, select future learning tasks with a similar amount of support and guidance (i.e., continue practicing) or with specific help on aspects of performance that yet need to be improved; if you are able to independently perform unsupported learning tasks, select more difficult future learning tasks. Giving both advice and some control to learners has positive effects on their motivation and self-efficacy, and it makes the training system more robust for unexpected events since human intervention can take dynamic learner characteristics such as fatigue and ad hoc preferences into account (Norman, 2007).

In conclusion, the coaching protocol should not only prescribe strategies that help learners develop SDL skills, but also specify how to scaffold the application of these strategies; that is, how to gradually decrease support and guidance as the learner’s SDL skills develop. In general, learners should be given strong guidance and advice at the beginning of the training program and only minimal prompts to use their SDL skills at the end of it. The ultimate goal of a training system with shared control is that learners not only acquire domain-specific skills, but also SDL skills. These skills are best learned in an integrated fashion and *both* types of skills need well-designed instruction to be developed. In a training system with shared control, a database with learning tasks development portfolio, and coaching protocol make the simultaneous acquisition of domain-specific and SDL skills possible.

Discussion

In this chapter, we posited that in technologically advanced domains such as ATC, training systems should apply the principles of shared control. This allows for the integrated development of domain-specific skills and SDL skills, including the formulation of learning needs, the identification of individual goals, and the selection of learning tasks for learning. These SDL skills are critical for maintaining expertise and being able to flexibly adapt to changes in technologies, working procedures, and regulations. According to our analysis, training systems with shared control are more effective for the development of SDL skills than non-adaptive systems and adaptive training systems with either full system control or full learner control.

SDL skills do not develop spontaneously but require support and guidance in a well-designed learning environment for their effective development (Zimmerman, 2002). As learners' SDL skills further develop, the control over needs identification, goal setting, and task selection gradually shifts from system to learner, thus, the learner takes increasing responsibility over her/his own learning process. Eventually, the learner must be able to identify her/his own concrete individual learning needs on the basis of self-assessments and – possibly deviant – assessments made by others who use given criteria and standards, set realistic and feasible learning goals to fulfill identified learning needs, and select appropriate new learning tasks that help reach the learning goals.

The three main components in a training system with shared control are a database with learning tasks, a development portfolio, and a coaching protocol (Kicken et al., 2008). The database contains learning tasks with metadata and allows for the repeated selection of appropriate learning tasks from a broad set of available tasks. In a cyclical process, selected tasks are performed by the learner and assessments are gathered in the development portfolio, making it possible to identify individual learning needs, set new learning goals, and select new tasks that help reach these goals. The coaching protocol prescribes strategies to support and guide the development of SDL skills in a systematic fashion. In our view, the ideas presented in this chapter are applicable to training programs in a wide range of complex, technologically advanced domains. Professionals such as medical specialists, aircraft pilots, and power plant controllers must all maintain their expertise in a process of lifelong learning because they are continuously confronted with fundamental and far-reaching developments in their domain.

Future research is needed on the coaching protocol, the central component of a training system with shared control. First, such research should study the effectiveness of different strategies for achieving SDL skills. For example, strategies that are known to help learners select appropriate learning tasks take variables such as previous task performance, mental effort, difficulty level, and available support and guidance into account (Salden et al., 2004; Corbalan et al., 2008; Van Merriënboer & Kirschner, 2013), but other variables such as motivation, fear of failure, and self-efficacy might be equally important. Second, the implementation of the coaching protocol is a major operation. Further research is needed to specify the interfaces between the coaching protocol, the database with learning tasks (i.e., task metadata), and the development portfolio (i.e., assessment information). In addition, research should provide more specific guidelines on how to best integrate the coaching of domain-specific skills and SDL skills. Third, research is needed on the professionalization of coaches for their new roles. Coaches have traditionally worked in non-adaptive training systems or training systems with a high degree of system control, paying little attention to the learners' SDL skill development. Training of coaches is, thus, necessary to prepare them for their new role in guiding the development of SDL skills in their learners (Beijaard, Verloop, & Vermunt, 2000; Isaacs, 1999; Katz & Assor, 2007).

The main conclusion here is that an adaptive training system with shared control is necessary to prepare learners for their work in complex and technologically advanced domains such as ATC. In contrast to non-adaptive training systems, an adaptive system acknowledges the fact that the 'average learner' does not exist, and in contrast with other adaptive training systems, it provides good opportunities to help learners develop their SDL skills. Such SDL skills are prerequisite for maintaining expertise and for lifelong learning in complex professional domains. The critical component in a training system with shared control is the coaching protocol which describes the strategies that should be applied to help learners develop their SDL skills along with their domain-specific skills. More research on the strategies described in the coaching protocol is needed.

CHAPTER 5

Fostering Self-regulation in Training Complex Cognitive Tasks

In complex cognitive domains, such as air traffic control, professionals must be able to adapt to and act upon continuing changes in a highly advanced technological work environment. To function optimally in such an environment, the controllers must be able to regulate their learning. Although these regulation skills should be part of their training, this is not usually the case. This study evaluates a training program that integrates air traffic control skills with regulation skills. The participants were 29 air traffic control students who followed either the original training program (*n* = 12) or a new program (*n* = 17) in which the development of regulation skills was embedded in the training of domain specific skills. Compared to students in the original program, the students in the new program showed increased self-efficacy in the use of self-regulated learning skills with improved performance in domain specific competences. An increase in self-directed learning skills, however, was not found. The implications of these findings are discussed with regard to the daily training practice of complex cognitive skills.

This chapter is based on: Van Meeuwen, L. W., Brand-Gruwel, S., Kirschner, P. A., De Bock, J. J. P. R., & Van Merriënboer, J. J. G. (2013). Fostering self-regulation in training complex cognitive tasks. Manuscript submitted for publication.

The nature of complex dynamic domains demands that experts in those domains keep up with developments in the relevant technologies and the regulations governing them. Air traffic control (ATC) falls into this domain. The continuous increase in air traffic (Eurocontrol Statfor, 2010) is accompanied by changes in regulations for airline and air traffic safety, pollution, and noise abatement. To deal with these changes, technologies are developed and introduced into the running system with the requirement that human action will adapt perfectly. This combination requires professionals who, to maintain competency, are able to continue learning throughout their careers (Bolhuis, 2003) despite the rapidly changing world around them (Jha, Bisantz, Parasuraman, & Drury, 2012; Van de Merwe, Oprins, Erikkson, & Van der Plaat, 2012; Van Merriënboer, Kirschner, Paas, Sloep, & Caniëls, 2009). Regulation skills increase the awareness of the experts regarding shortcomings in performance, which can motivate them to address these shortcomings in training programs (Eva & Regehr, 2005; 2008). Therefore, in training a prospective air traffic controller, specific attention should be paid to the development of regulation skills that prepare them for continuous learning (Bolhuis, 2003; Candy, 1991). However, training does typically not focus on these skills, which raises two questions: How can students in a complex cognitive domain learn these skills while they learn complex domain-specific competencies? Will these skills positively affect domain-specific learning outcomes? The objective of this study is to investigate a training design that integrates the development of both students' regulation skills and their domain specific competences. The development of regulation skills and domain-specific competences are compared between an original training program and an integrated training program. Before we can answer the questions posed above, we must define the *regulation-of-learning* skills that prepare for continuous learning and describe how training and training tools can be designed to foster the development of these skills.

Regulation of Learning

Self-regulated learning (SRL) skills in combination with self-directed learning (SDL) skills allow experts to critically evaluate their performance and choose learning activities that fit their learning needs (Brand-Gruwel, Kester, Kicken, & Kirschner, 2013; Van Meeuwen et al., in press, see Chapter 4). SRL comprises strategies that can be classified according to Zimmerman's five phases (1986; 1990): (1) *orienting* towards the task, (2) *planning* performance before starting the task, (3) *monitoring* task performance while performing the task, (4) *adjusting* task performance, and (5) *evaluating* task performance after the task has been finished.

However, SRL is not isolated; other factors that relate to the assessment of past performance and the setting of a future learning trajectory also influence students' SRL behavior. Knowles (1975, p. 18) defined SDL as "a process in which individuals take the initiative, with or without the help from others, in diagnosing their learning needs, formulating goals, identifying human and material resources, choosing and implementing appropriate learning strategies, and evaluating learning outcomes." Hence, SDL comprises more than SRL does (Loyens, Magda, & Rikers, 2008). SDL includes the students' ability to not only define learning needs and the required learning resources (i.e., *self-directing*; Candy, 1991) but also *take initiative* in this process (Stockdale & Brockett, 2011). The relevant literature shows that both SRL skills and SDL skills are useful in preparation for working in a continuously evolving environment (Bolhuis, 2003; Candy, 1991).

Because training in SRL and SDL skills is a goal, it is important to be cognizant of the factors that foster the development of these skills. Pintrich and De Groot (1990) showed that students' *self-efficacy* is positively related to these *self-regulation* processes (i.e., SRL and SDL). *Self-efficacy* is the belief that one is capable of carrying out a task (Schunk, 1985). It can be subdivided into *self-efficacy for learning* a task, *self-efficacy for performance* on a task, and the appraisal of the *task value* in learning (Lodewyk & Winne, 2005). Students' self-efficacy and self-regulation processes are the best predictors of performance (Pintrich & De Groot, 1990). We next describe how focusing on the development of these skills can be achieved by considering this development in *training design*.

Training Design to Foster Self-regulation

The design of a training program should meet the need to foster the development of students' *self-efficacy* and self-regulation in the training of complex cognitive skills. Hence, the design must take into consideration that mastery is a positive experience and students must learn to self-regulate and self-direct their learning. To improve learning outcomes, it is advisable to let students *take initiative* in the entire process of directing and regulating their learning by giving them the opportunity to do so (i.e., learner control over task selection) (Corbalan, et al., 2008; 2010; Corbalan, Van Merriënboer, & Kicken, 2010; Van Meeuwen et al., in press, see Chapter 4). To self-direct learning, students must be able to evaluate their learning outcomes by doing self-assessments and diagnosing their learning needs in addition to learning how to formulate their learning goals and select resources for learning (i.e., learning tasks and coaching). However, such learner control requires SRL and SDL skills, which students do not have by nature (Salden, Paas, & Van Merriënboer, 2006; Corbalan, Van Merriënboer, & Kicken, 2010). The *shared control* over future learning solves this paradox. In a shared control learning environment, the student and the system (e.g., coach) share the responsibility of future learning, and students gradually learn to become aware of their learning needs and of matching them with possible task characteristics (Corbalan et al., 2010; Van Meeuwen et al., in press, see Chapter 4). To self-regulate learning, students must learn how to learn optimally from a learning task and plan their actions accordingly. Monitoring and adjusting this performance then helps students to reach the defined learning goals. To give students positive experiences of mastery, learning tasks must be selected that optimally fit individual learning needs. The more *self-efficacy*, *SRL* skills, and *SDL* skills a student has, the more s/he can control future learning.

Development portfolio. A *development portfolio* can support self-directed and self-regulated learning (i.e., the basis for continuous learning) (Figure 5.1) and can support the shared control over selecting learning tasks that optimally fit individual learning needs (Kicken, Brand-Gruwel, & Van Merriënboer, 2008). The top of Figure 5.1 shows the important elements of the development portfolio. The information about learning tasks (i.e., *metadata*) in combination with regulation *prompts* can give the student insight into their performance status. Based on the information in the portfolio, students are supported to self-direct learning (i.e., set learning goals and select appropriate tasks for learning) and while performing those selected tasks, they are supported to regulate their learning. If the selected learning tasks match the students' learning needs, this can increase students' self-efficacy (Zimmerman 2000).

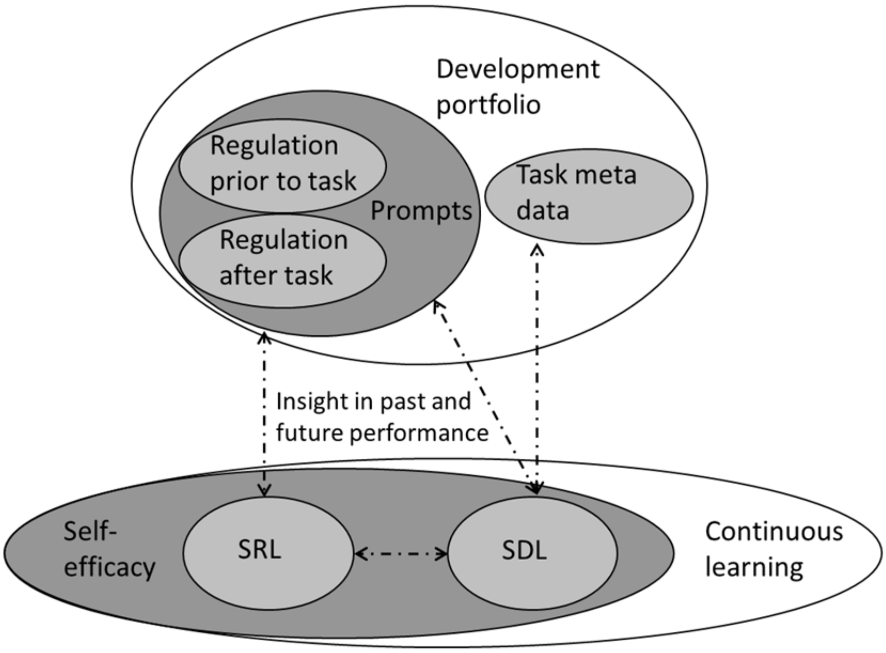


Figure 5.1 *Elements in a development portfolio in relation to SRL, SDL, self-efficacy, and continuous learning.*

Metadata. For planning future learning, the portfolio comprises information about all available learning tasks (i.e., so called *metadata*), thus informing the user about the training characteristics of all tasks that can be used in planning future learning/performance. This metadata should contain details about all characteristics of the variety of tasks. The *four components instructional design model* (Van Merriënboer, 1997) identified at least four characteristics that should be used in planning future learning. This information should thus be part of the metadata. First, a task is characterized by its complexity. In ATC, the complexity is mainly determined by the number of aircraft per unit of time and the number of potential conflicts, changes in runway use, and changes in weather conditions. In addition, non-nominal situations (e.g., emergencies) can increase the complexity of tasks. Second, the coach can provide support to lower the tasks' training load. This support can vary from full support (i.e., worked examples) to no support (i.e., exam tasks). Third, specific supportive information can be required for the task (e.g., in ATC, new call signs, specific communication by radio telephony, specific aircraft performances, etc.). If so, it can influence the task preparation process. Hence, the information should be studied in advance, which should thus be stated in the metadata. Fourth, the task can focus on training in a specific competence or skill (e.g., part task training), or it can be authentic and train for a range of competences. Therefore, the metadata should indicate which competences can be trained.

Prompts. To foster students' self-regulation and self-direction in learning, the development portfolio contains learning task worksheets, including the metadata and *regulation prompts.* At the right moments in the learning process, the development portfolio prompts the students to use the metadata to either orientate towards their future learning performance (prompts prior to the learning task) or evaluate their past learning performance (prompts after the learning task) and then plan future learning performances. Previous research has shown that this is an effective way to train students' SDL and SRL skills (Jossberger, Brand-Gruwel, Boshuizen, & Van de Wiel, 2010).

Hypotheses

The main research question is as follows: What is the effect of a *training program* in which a development portfolio comprising metadata and regulation prompts are embedded on students' *self-efficacy*, *SRL skills*, *SDL skills*, and *task performance*?

It is expected that this kind of training program would make it possible to involve students in regulating and delineating their learning (Corbalan et al., 2010; Van Meeuwen et al., in press, see Chapter 4) and increase their regulation activities (Hypothesis 1). Specifically, it is expected that the training program would improve the following measures/competences: students' *self-efficacy* (self-efficacy in performance, self-efficacy in learning, task-value (Hypothesis 1a); students' SRL skills (i.e., orientation to task, planning performance, monitoring performance, and evaluating performance (Hypothesis 1b); and students' SDL skills (i.e., self-direction by defining learning needs and learning recourses and taking initiative (Hypothesis 1c). Moreover, because of better *self-efficacy*, SRL, and SDL*,* we expect students to show better task performance than the students in a program focusing on ATC skills only (Hypothesis 2).

Method

Setting

This study was situated in the domain of ATC and focused on radar-based ATC training (i.e., area control surveillance; ACS). This comprises the training for area control of inbound and outbound air traffic at the Amsterdam Airport Schiphol and crossing aircraft to a flight level of 24,500 feet (approximately 7,500 meters). The ACS training program consists of seven weeks of simulator training in which students in small groups of three or four students perform tasks supervised by a coach. During these seven weeks, each student runs through 50 radar simulator tasks 40 minutes in length, which provide the basic skills in area control surveillance. Training complexity increases in five main *training steps*. Each step comprises approximately 10 learning tasks. For each learning task, *briefing* and *debriefing* periods take place.

Participants

The participants in this study were 29 students participating in an ACS course (Air Traffic Control the Netherlands). All participants had nine months of training experience in ATC (age $M = 23.00$ *years,* $SD = 2.41$; 20 males, 9 females). For two and a half years, all regular students enrolled in the course on area control surveillance at Air Traffic Control the Netherlands participated in this study. During the first year, the original training program was run (*original condition;* $n = 12$; 10 males and 2 females). In the second and third years, the integrated training program was run (*integrated condition;* $n = 17$; 10 males and 7 females).

Materials

Intervention. The aim of the integrated training program was to foster students *self-efficacy*, *SRL*, and *SDL* concurrently with the development of competence in ACS *performance*. In order to foster students' *self-efficacy*, SRL, and SDL*,* different educational elements were embedded in the original training program. The simulator tasks were redesigned and provided with metadata. Furthermore, process worksheets were developed and provided to the students in order to increase their involvement. The *worksheets* gave the students learning task information (e.g., metadata) and prompted them for regulations before the learning tasks' briefing and debriefing. The metadata and the worksheets yielded insight into the personal development of each student and comprised the *development portfolio* (Kicken et al., 2008). For an overview of the intervention, see Figure 5.2.

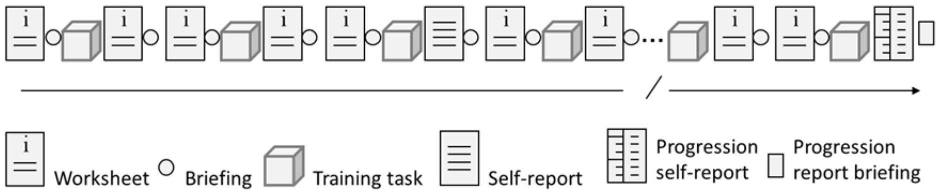


Figure 5.2 *Intervention: An example of a training step.*

Worksheets and self-reports. A set of process worksheets and self-reports supported the intervention aimed to foster *SRL* and *SDL.* This material prompted students both in preparation for the task and after completion of the task regarding regulations for the learning tasks' briefing moments. Students' self-regulation and self-direction in learning was prompted in three possible moments in the training: (1) prior to the learning task briefings (i.e., by *learning task worksheets*); (2) after each third learning task (i.e., by *learning task self-reports*), and (3) at the end of each training step, prior to the progression report meeting (i.e., by *progression self-reports; PR-briefing)*. For an overview, see Figure 5.2.

Learning task worksheets. The learning task worksheets were divided into three parts (Appendix I shows a sample training-task worksheet). At the top of the sheet were metadata on training goals, traffic complexity (e.g., regional, inbound, and outbound crossing traffic) and task variables, such as weather conditions, runways in use, and training competencies (e.g., traffic flow, communication, perception). The second part provided preoperational regulation prompts, which asked students to think about individual training goals, how to reach them, and what they expected from the coach. Both parts prepared the student for the learning task. The third part included questions on performance and the implications for further training. The students answered these questions immediately after the learning task, which prepared them for the debriefing.

Learning task self-reports. Students filled out the learning task self-reports every third learning task. The report was divided into two parts (Appendix II). First, the report asked for an evaluation of the progress on 14 ATC main competences (described in the next subsection). The students were then asked to indicate the points of special interests that should be worked on in the next learning tasks, how to carry them out, and the support they expected from the coach. The self-report asked students to evaluate the progression of the prior three tasks by checking the individual learning task worksheets. This report also prepared the students for the learning task debriefing and therefore was filled out immediately after the learning task (i.e., instead of the last regulation prompt on the worksheet). Next, the self-reports of two learning tasks provided data for one progress self-report.

Progress self-reports. Oprins and Schuver (2003) and Oprins, Burggraaff, and Van Weerdenburg (2006) designed an ATC performance model to measure ATC performance. The model distinguishes factors in information processing (i.e., perception, interpretation, dividing attention, planning and decision making), actions (i.e., communication, coordination, label and strip management, and equipment operation), outcome (i.e., safety and efficiency), and influences (i.e., workload management, teamwork ability, and others like motivation). The application of this model allows the formulation of performance criteria on all four aspects and several sub-aspects. For example, safety is divided into three performance criteria: maintains separation minima correctly; builds in sufficient safety buffers; and switches from monitoring to vectoring in time (Oprins et al., 2006, p. 307). In this way, ATC performance of 14 competences can be scored based on 62 sub aspects of the performance criteria. The progress self-reports assessed the 62 observable variables. It stimulated students to think about their progress on all assessment items. Students filled out the report at the end of each training step, which prepared them for the upcoming *progress report meeting*.

Coaching. Coaching concentrated on briefing and debriefing the learning tasks and the progression report meetings. The learning task worksheets and self-reports ensured that the briefing and meetings focused on the learning challenges of the learning tasks. In the integrated program, the worksheets and self-reports prepared the students for the meetings. Consequently, they were able to contribute from their point of view, instead of only receiving information from their coach.

Original program. In the original program, students were not equipped with the development portfolio (i.e., learning task worksheets, learning task self-reports, progression self-reports), so they went through their training program without a metadata overview, and they were not prompted for regulations by the worksheets. Apart from the intervention itself and an update on airspace, all other aspects, such as training period (i.e., seven weeks), number of assignments per student (i.e., 50), examination (according to the Eurocontrol Specification, 2008), difficulty of pre- and post-test assignments (i.e., the number of aircraft and number of potential conflicts), and the moments of coaching were similar.

Self-efficacy questionnaire. A Dutch translation of the "Self and Task Perception Questionnaire" (STPQ; Lodewyk & Winne, 2005; Appendix III) was used to measure *self-efficacy*. It was translated and validated with the permission of the authors. The original English version of this scale comprises 20 items. The self-efficacy items were based mainly on the motivated strategies for learning questionnaire (Pintrich, Smith, Garcia, & McKeachie, 1991). After translation into Dutch, the scale was re-translated into English to confirm the correct interpretation of the items. No differences in interpretation were found. Next, the Dutch translation was administered to 80 candidates in ATC training in The Netherlands (mean age = 23.4 years, *SD* = 2.40; 66 males, 14 females). The confirmatory factor analysis resulted in three constructs: (1) measuring the sense of task agency, that is, s*elf-efficacy for performance* (6 items; Cronbach's alpha = .83) (e.g., *Knowing the difficulty of this project, the teacher, and my skills, I think I will do well on this task*; *I expect to do well on this task*); (2) measuring the sense of future mastery, that is, '*self-efficacy for learning*' (7 items; alpha = .73) (e.g., *I'm confident I am learning the basic ideas in this task*; *I am enjoying the learning in this task*), and (3) measuring the personal interest in the task, that is, '*task value*' (5 items; alpha = .62) (e.g., *Understanding the material of this task is important to me*; I *am interested in the material of this task*).

ATC assignment. Two 10-minute simulator tasks in ATC were designed for each program. The first task fits the expected level of performance at the start of the course (i.e., the number of aircraft was low, with a minimum number of conflicts). The second task fits the expected performance level at the end of the course (i.e., a high number of aircraft with several possible conflicts ahead). These tasks contained both inbound and outbound traffic in the simulated environment of area control. The task was to maneuver the air traffic safely and efficiently to the indicated destinations. One experienced coach observed assignment *performance*. The tasks were divided into two phases: in the first minute, enough information was provided to allow students to orient to and plan the task. The performance phase was carried out in the remaining nine minutes.

Cued retrospective report. Cued retrospective reporting (CRR) was used to measure the students' SRL-levels (Van Gog, Paas, Van Merriënboer, & Witte, 2005). During the ten-minute ATC assignment, the students' eye-movements were recorded with a Tobii 1750 eye-tracker that was connected to the ATC simulator. After the assignment, students watched their eye movements superimposed on the recording of the moving traffic situation. The eye movements and the traffic situation were played back at 75% of the actual speed. While they watched the replay, the students were asked to verbalize the thoughts they had during the assignment. If they were silent, they were prompted to keep talking about what they thought. The so called "gaze replay" showed the eye fixations based on the standard Tobii® studio fixation filter. A 25% delayed replay of the audio from the radio-telephony interaction supplemented the visual cue. The verbalizations from the CRR were recorded and transcribed. The CRR data from one student in the original condition were missing because of a recording error.

Coding scheme for SRL. An inductive-deductive method was used to develop the coding scheme to measure the amount of SRL reported in the CRR (an overview of the coding scheme is shown in Table 5.1). The coding scheme was based on the five components of Zimmerman's SRL theory (1986, 1990): *orientation*, *planning*, *monitoring*, *adjusting*, and *evaluation*. Studying the transcriptions, however, showed the need to divide the evaluation category into five sub-categories: *reflective evaluations* (e.g., I have been thinking a while which flight level to give this aircraft); *error analysis* (i.e., negative evaluations; e.g., I directly felt punished that I had set about that conflict so clumsily); *positive evaluations* (e.g., I had that part under safe control, I could easily close my eyes for a while); *learning evaluation* (i.e., evaluative utterances on learning; e.g., I just tried something different. I put him as last in line, just to learn from the situation if something goes wrong.). The use of CRR yielded retrospective evaluations *on task performance* (e.g., Retrospectively, I should have given him an expedite climb). An interrater reliability analysis using the kappa statistic was performed on 10% of the transcriptions to determine consistency between two raters. Interrater reliability was acceptable, Kappa = .73; all remaining protocols were scored by one rater.

Table 5.1 *Hypotheses and Corresponding Dependent Variables and Measurement Materials*

Hypothesis	Main variable	Sub variable	Material
H1 (Regulation)			
1a	Self-efficacy	For learning	Self-efficacy questionnaire
		For task value	
		For performance	
1b	SRL	Orientation	Cued retrospective report *and coding scheme*
		Planning	
		Monitoring	
		Adjusting	
		Evaluation in action: reflection	
		Evaluation in action: error analysis	
		Evaluation in action: positive	
		Evaluation on learning	
		Evaluation on performance	
		Self-assessment accuracy	62-items assessment form
1c	SDL	Taking initiative	SDL questionnaire
		Responsibility for learning	
H2 (Performance)			
	Performance progress score		62-items assessment from course assessment

Scoring ATC assignment. To measure the ATC performance, 14 competences were scored based on the 62 sub aspects of the performance criteria, resulting in a final performance score between 0 and 100% (Oprins, 2008).

Self-assessment accuracy. To measure the accuracy of self-assessment, the coach and the student assessed the ATC assignment *performance* on the 62 items assessment form for ATC competences (Oprins et al., 2006). Six competences were relevant for these short tasks, and they were assessed by both the coach and the student (i.e., safety, traffic flow, communication, mental model, planning, and decisiveness). A four-point Likert scale was used to score the *performance* (1 = unsatisfactory; 2 = insufficient; 3 = sufficient; 4 = good). The absolute difference between the coach's score and the student's score provided the measure of *self-assessment quality*; the smaller the absolute difference (i.e., either overrated or underrated), the higher the self-assessment quality.

SDL questionnaire. A Dutch translation of the "Personal Responsibility Orientation Self-Directed Learning Scale" (PRO-SDL; Stockdale & Brockett, 2011; Appendix IV) was used to measure *SDL skills*. The original English version measures four factors with 25 items: initiative, control, self-efficacy, and motivation. This version was translated and validated with the permission of the authors. After translation into Dutch, the scale was translated back into English to confirm the correct interpretation of the items. No differences in interpretation were found. Next, the Dutch translation was administered to 158 undergraduates in aviation studies (mean age = 19.4 year, *SD* = 1.79; 143 males, 15 females). The confirmatory factor analysis resulted in two constructs: a scale focusing on *self-directing* (i.e., responsibility for learning; 8 items; alpha = .79) (e.g., *I am very confident in my ability to independently prioritize my learning goals; I am very convinced I have the ability to take personal control of my learning*) and a scale focusing on *taking initiative* (4 items; alpha = .69) (e.g., *I always effectively take responsibility for my learning*; *I would rather take the initiative to learn new things in a course rather than wait for the instructor to foster new learning*).

Performance progress score. To measure the *performance progress score*, two course assessments were available at the start and at the end of the ACS training period. The scores were based on the 62-item form for the assessment of all 14 ATC competences, which resulted in a performance progress score between 0 and 100% (Oprins et al., 2006).

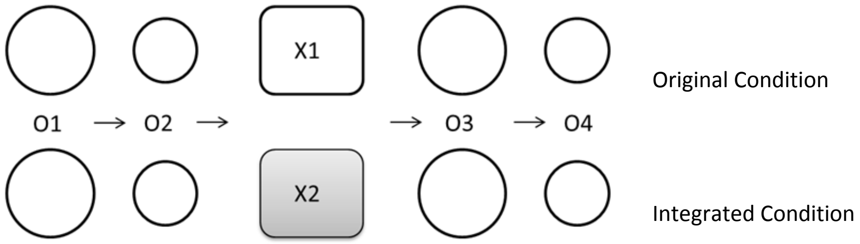
Design and Procedure

The measurements of the variables, the influence and development of *self-efficacy*, *SRL*, and *SDL*, took place in individual pre- and post-60 minute measurement sessions at the beginning and at the end of the training (see Figure 5.3). The sessions were designed as follows: First, the students were told that the performance in this session would not influence their assessment in the ATC training. They were asked to answer some demographic questions, and they received the Dutch PRO-SDL questionnaire. Next, they were informed about the start situation of the task, they received the corresponding flight strips (i.e., paper strips corresponding to the traffic containing relevant flight information), and they were allowed to orientate to the situation for one minute. Based on the given information, they were asked to fill out the Dutch self-efficacy questionnaire in which the first cued retrospective report concerned the first minute of orientation. The remaining nine minutes of the task were then run, after which both the coach and the students assessed the performance separately. The session was closed with a CRR of the complete second part of the task.

The pre-measurement session took place at the end of the first simulator training step, followed by course assessment one. The post-measurement session took place in the fifth simulator training step, followed by course assessment two (For an overview, see Figure 5.3).

Data Analysis

To answer the question whether the intervention affected the students' *self-efficacy* (Hypothesis 1a), *SRL-skills* including self-assessment (Hypothesis 1b), SDL skills (Hypothesis 1c) and *performance* (Hypothesis 2), the increases from the pretest to the posttest between students in the original condition and students in the integrated condition were compared. In all analyses, non-parametric independent sample tests were calculated. In the analyses reported here, unless indicated differently, a one-tailed significance level of .05 was used with $N = 29$ (i.e., original condition $n = 12$; integrated condition *n* = 17) or less if indicated, due to missing values. The median rank (*Mdn*), the range of rank numbers, Mann-Whitney (*U*), *z*-score, level of significance (*p*), and effect size (*r*) are given.



O1 = O3 = PRO-SDL Questionnaire
ATC Assignment (first minute)
STPQ Questionnaire
ATC Assignment (remaining 9 minutes)
Self-assessment + Coach-assessment
Cued Retrospective Report
O2 = Course Assignment 1
O4 = Course Assignment 2
X1 = Original Training Program
X2 = Integrated Training Program

Figure 5.3 *Procedure.*

Results

Self-efficacy

In order to test Hypothesis 1a (i.e., increase of self-efficacy), the differences in the increase of self-efficacy scores were compared between the original condition and the integrated condition. Table 5.2 provides the results. The analyses revealed no effects on increase of *self-efficacy for performance* (*n* = 29, *U* = 82.50, *z* = -.871, *p* = .199, *r* = -.16). However, a medium effect was found on increase of *self-efficacy for learning*. The increase in self-efficacy for learning in the integrated condition (*Mdn* = 20, range 1-29) is significantly larger than in the original condition (*Mdn* = 10, range 4-23, *U* = 57.50, *z* = -2.00, *p* = .023, *r* = -.37). There was also a large effect on increase of *self-efficacy for task value*. The increase in the integrated condition (*Mdn* = 20, range 3-29) is significantly larger than in the original condition (*Mdn* = 8.5, range 1-28, *U* = 37.50, *z* = -2.91, *p* = .001, *r* = -.54), indicating that the intervention positively affected the increase of self-efficacy for learning and an increased interest in the task.

Table 5.2 *Means and Standard Deviations of Increase of Self-efficacy Measures (STPQ)*

	Original condition (*n* = 12)			Integrated condition (*n* = 17)		
	M (SD)			*M (SD)*		
	Increase	Pre	Post	Increase	Pre	Post
Self-efficacy for performance	.33 (2.19)	19.67 (1.67)	20.00 (2.37)	1.24 (2.39)	21.59 (1.87)	22.82 (1.91)
Self-efficacy for learning**	-.50 (1.09)	27.92 (1.88)	27.42 (1.24)	.65 (2.76)	28.59 (1.70)	29.24 (2.33)
Self-efficacy for task value**	-.58 (1.98)	19.33 (2.39)	18.75 (1.14)	1.18 (1.74)	18.35 (1.36)	19.53 (1.37)

**p* < .10. ***p* < .05.

Table 5.3 *Means and Standard Deviations of Increase of Self-regulated Learning Measures*

	Original condition (*n* = 11)			Integrated condition (*n* = 17)		
	M (SD)			*M (SD)*		
	Increase	Pre	Post	Increase	Pre	Post
Total regulative utterances**	-14.73 (25.87)	79.82 (26.31)	65.09 (13.33)	7.41 (16.66)	52.06 (12.70)	59.47 (13.88)
Orientation	-.64 (2.16)	3.00 (1.41)	2.37 (2.01)	.00 (2.50)	2.53 (1.55)	2.53 (2.87)
Planning*	-.27 (2.05)	3.64 (1.36)	3.36 (1.21)	1.47 (2.81)	4.00 (2.00)	5.47 (2.84)
Monitoring**	-11.27 (12.36)	32.18 (18.94)	20.91 (7.84)	1.18 (7.77)	18.94 (6.12)	20.12 (7.30)
Adjusting	-.91 (9.10)	26.36 (9.24)	25.45 (5.90)	3.59 (6.87)	13.41 (5.84)	17.00 (4.87)
Evaluation in action: reflection**	-.73 (3.04)	5.55 (3.11)	4.82 (2.14)	4.00 (3.32)	3.06 (1.71)	7.06 (3.58)
Evaluation in action: error analysis**	.18 (1.25)	.63 (1.03)	.82 (1.08)	1.18 (1.29)	.18 (.53)	1.35 (1.32)
Evaluation in action: positive	.09 (.83)	.18 (.40)	.27 (.65)	.35 (.86)	.18 (.53)	.53 (.72)
Evaluation on learning	-.64 (1.29)	.92 (1.30)	.27 (.47)	-.29 (1.36)	1.24 (.97)	.94 (.90)
Evaluation on performance	-.81 (5.43)	7.36 (7.38)	6.55 (4.57)	-1.58 (4.76)	8.53 (3.76)	6.94 (4.26)

**p* < .10. ***p* < .05.

Self-regulated Learning

In order to test Hypothesis 1b (i.e., increase of SRL including self-assessment), the increase of SRL scores between the original condition and the integrated condition was compared. The results summarized in Table 5.3 show a medium effect on increase of *total SRL*. The increase in total reported regulative utterances in the integrated condition (*Mdn* = 19, range 5-28) was significantly greater compared to the original condition (*Mdn* = 8, range 1-27, *U* = 39.50, *z* = -2.542, *p* = .006, *r* = -.480). With respect to the increase of specific regulative activities, no effect between the two conditions was found on the increase of *orientation* (*U* = 80.50, *z* = -.619, *p* = .268, *r* = -.117). A medium effect was found on the increase of *planning* activities: The integrated condition (*Mdn* = 17, range 4-28) increased marginally significant more than the original condition (*Mdn* = 9, range 1-28, *U* = 60.00, *z* = -1.598, *p* = .055, *r* = -.302). A large effect was found on the increase of *monitoring* activities: The integrated condition (*Mdn* = 19, range 6-28) increased significantly, compared to the original condition (*Mdn* = 7, range 1-25, *U* = 34.50, *z* = -2.780, *p* = .003, *r* = -.525). No effect between the two conditions was found on the increase of *adjustment* activities (*U* = 67.50, *z* = -1.226, *p* = .110, *r* = -.232). Effects were found on the increase of *evaluation* activities, including a large effect on the increase of *reflective evaluation* activities in which the integrated condition (*Mdn* = 20, range 8-28) increased significantly compared to the original condition (*Mdn* = 6, range 1-18, *U* = 25.50, *z* = -3.226, *p* = .001, *r* = -.610). A medium effect was found on the increase of *error analysis* activities in which the integrated condition (*Mdn* = 18, range 10-28) increased significantly compared to the original condition (*Mdn* = 6, range 1-25, *U* = 48.50, *z* = -2.240, *p* = .013, *r* = -.423). The results showed no effects between the two conditions on the increase of *positive evaluation* (*U* = 76.50, *z* = -.892, *p* = .187, *r* = -.169), the increase of *evaluation of learning* (*U* = 87.50, *z* = -.291, *p* = .386, *r* = -.055), and the increase of *evaluation of performance* (*U* = 79.00, *z* = -.684, *p* = .247, *r* = -.129). These results indicate that the intervention program positively affected the increase of students' SRL *planning, monitoring, reflective evaluation,* and *error analysis* skills but not the increase of their *orientation, adjusting, positive evaluation, evaluation on learning,* and *evaluation on performance* skills.

Self-assessment accuracy. Table 5.4 shows a summary of the results. The results show no differences between the conditions on the increase in self-assessment accuracy in safety (*U* = 66.00, *z* = -.859, *p* = .195, *r* = -.17) traffic flow (*U* = 87.00, *z* = -.306, *p* = .380, *r* = -.006), communication (*U* = 80.00, *z* = -.251, *p* = .401, *r* = -.05), mental model (*U* = 83.00, *z* = -.494, *p* = .311, *r* = -.09), planning (*U* = 88.00, *z* = -.259, *p* = .385, *r* = -.05), and decisiveness (*U* = 61.00, *z* = -.876, *p* = .191, *r* = -.17).

Table 5.4 *Means and Standard Deviations of Self-assessment Accuracy Measures*

	Original condition *M (SD)*				Integrated condition *M (SD)*			
	Increase	|Pre|	|Post|	*n*	Increase	|Pre|	|Post|	*n*
Safety	-.03 (.52)	.48 (.36)	.45 (.42)	11	.09 (.25)	.32 (.25)	.43 (.18)	15
Traffic flow	.03 (.47)	.48 (.39)	.51 (.14)	11	.02 (.37)	.38 (.22)	.41 (.17)	17
Communication	-.12 (.33)	.49 (.18)	.37 (.32)	10	-.13 (.41)	.46 (.34)	.33 (.20)	17
Mental model	-.18 (.40)	.51 (.38)	.33 (.24)	11	-.13 (.44)	.45 (36)	.32 (.25)	17
Planning	-.11 (.49)	.55 (.43)	.44 (.31)	11	-.08 (.35)	.44 (.31)	.36 (.26)	17
Decisiveness	.21 (.59)	.61 (.52)	.39 (.25)	11	.02 (.46)	.39 (.28)	.41 (.31)	14

Self-directed Learning

In order to test Hypothesis 1c (i.e., increase of SDL) the differences in the increase of SDL scores were compared between the original condition and the integrated condition. Table 5.5 provides a summary of the results. No effects are found for SDL measures. Development in SDL-*taking initiative* (*U* = 91.50, *z* = -.474, *p* = .323, *r* = -.009) and SDL-*responsibility for learning* (*U* = 91.00, *z* = -.495, *p* = .316, *r* = -.009) are similar in both the original and the integrated condition, indicating that the intervention program did not affect students' SDL skills.

Table 5.5 *Means and Standard Deviations Self-directed Learning Measures (PRO-SDL)*

	Original condition (*n*=12)			Integrated condition (*n*=17)		
	M (SD)			*M (SD)*		
	Increase	Pre	Post	Increase	Pre	Post
SDL-Taking initiative	-.75 (1.91)	14.67 (2.27)	13.92 (1.44)	-.47 (1.23)	14.88 (1.45)	14.41 (2.06)
SDL-Responsibility for learning	-1.17 (2.08)	32.67 (2.35)	31.50 (2.43)	-.71 (1.79)	33.24 (2.25)	32.53 (2.62)

Performance Progress Score

In order to test Hypothesis 2 (i.e., increase of performance as measured by the course assessment), the differences in progress scores (i.e., differences between assessment one and assessment two) were compared between the original condition and the integrated condition. The results, which are summarized in Table 5.6, show a medium effect in the students' *performance progress scores*. The integrated condition (*Mdn* = 20, range 2-29) showed significantly greater progress than the original condition did (*Mdn* = 11, range 1-26), *U* = 60.00, *z* = -1.863, *p* = .032, *r* = -.35.

Table 5.6 *Means and Standard Deviations Performance Progress Measure*

	Original condition (*n*=12)			Integrated condition (*n*=17)		
	M (SD)			*M (SD)*		
	Increase	Pre	Post	Increase	Pre	Post
Performance progress score** (1-100)	-2.42 (10.82)	87.67 (7.60)	85.25 (8.82)	4.53 (12.42)	78.88 (9.47)	83.41 (10.95)

**p* < .10. ***p* < .05.

Discussion and Conclusions

The aim of this study was to investigate the implications of integrating the training of students' regulation skills in a training program for domain specific skills in a complex cognitive domain. The results indicate that involving students in their learning process could result in improving regulation activities and better learning outcomes in complex cognitive tasks.

Hypothesis 1 stated that an integrated training program combining training in complex domain-specific competences and regulation skills increased both regulation activities and domain specific competences. The introduction of the integrated training program resulted in an increase in students' *self-efficacy* (H1a), *SRL* (H1b) and an increase in students' *performance* (H2). However, the expected increase in *SDL* skills (H1c) failed to appear.

In line with Hypothesis 1a., an increase was shown in *self-efficacy for learning* and *self-efficacy for task value*. Students in the integrated condition gained a more positive belief in how well they were prepared for the tasks, and they became more positive about their interest in the task. The sense of *self-efficacy for task performance* did not differ between the two conditions. Apparently, the students did not experience sufficient mastery of the learning tasks (Bandura, 1982; 1997).

In line with Hypothesis 1b, greater development was found in the use of SRL skills in the integrated condition than in the original condition. The integrated condition showed more SRL skills than the original condition in terms of *planning*, *monitoring,* and *self-evaluation* (*reflective evaluation* and *error analysis*). This result implies that the integrated condition increased in the ability to perceive own performance and to recognize mistakes made in that performance. Regarding the self-assessment accuracy, no differences were found between the conditions. This is an indication that improvement is needed in the quality of self-assessment and thus the instruction should change to foster this development more effectively.

We conclude that the integrated condition succeeded in training SRL competences and fostering self-efficacy more than the original program did. Two reasons are assumed to underlie the lag in SDL development. First, the training period of seven weeks might have been too short for the development of SDL skills. Previous research has shown that the development of SDL skills takes longer than weeks or even months (Salden, Paas, & Van Merriënboer, 2006) and appears only in expert learners (Ertmer & Newby, 1996). Furthermore, as realistic self-perception is an important prerequisite for developing SDL (Knowles, 1975; Van Meeuwen et al., in press, see Chapter 4) presumably more time is needed to develop both SRL and SDL. Second, the intervention might not have provided enough opportunities to completely direct own learning. Despite the regulation prompts to focus on learning needs and set learning goals in each learning task, full adaptive training (i.e., an individual is completely free to select the order of learning tasks) was not available. Hence, more tasks and a greater variety of tasks with the same complexity level are required to provide a genuine choice in task selection.

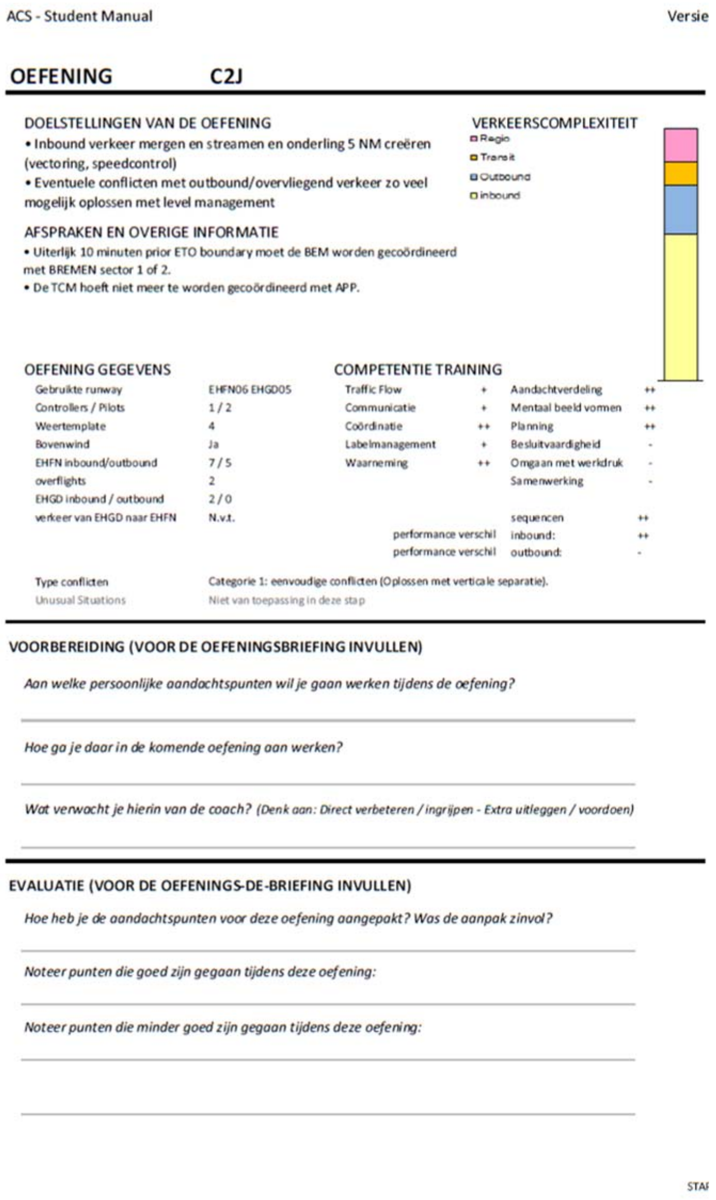
In line with Hypothesis 2, the improvement shown in performance progress score is promising. In the integrated program, the development of self-efficacy and SRL skills was achieved simultaneously with an increase in learning outcomes. This result is in line with earlier research by Kicken et al. (2008) and Kicken, Brand-Gruwel, Van Merriënboer and Slot (2009b), who studied the development of portfolio-based advice on task selection in a vocational training domain.

Some limitations were caused by the application of the research to real practice. First, the relatively short training period of the ACS (i.e., seven weeks) is a limitation of this study and could be an explanation for the failure of the development of SDL skills. Second, the design is limited with regard to the development of SDL skills. The worksheets involved students in their learning process, but they did not experience freedom in task selection. The delineation of learning needs and the translation to human and material resources for learning is of major importance in the development of SDL skills (Knowles, 1975). However, these skills can develop only when students experience choices in task selection. Third, the number of participants was limited. Fourth, because of circumstances, the ATC assignments, the learning tasks, and the course assessments used differed in two conditions because of changes in the simulated airspace used in training. Care was taken that the replacement ATC assignment and course assessments in the integrated condition were the same concerning complexity as those in the original condition. The eventual effects of the changes in the airspace might have disappeared when the results of the pre- and post-measurements were subtracted. For these four reasons, it is necessary to be careful in generalizing the results (the *performance progress scores* in particular) to other situations.

Two aspects of the present study are important for future research. First, future research could focus on freedom in task selection in a shared control-task selection training design. This is expected to foster not only the development of self-efficacy and SRL skills but could also foster the students' ability to understand the consequences of learning needs for the selection of learning tasks, thus increasing their SDL skills. In future studies of task selection, students' self-assessment skills will become a requirement for students. These skills would provide them with insight into their learning needs. Moreover, with better self-assessment skills, students will experience task mastery, which would foster their self-efficacy (Bandura, 1982; 1997). Second, future research should include a longer training period to allow SDL skills to develop and to monitor the long-term influence of students' regulation skills on the development of complex competences.

To conclude, the results of this study imply that the design of an integrated learning program is appropriate to develop both domain specific competences and regulation skills as preparation for continuous learning (Bolhuis, 2003; Candy, 1991). The elements of a well-designed development portfolio played a crucial role in successful training. The study showed that providing students with relevant metadata and fostering them to prepare and evaluate their learning activities both improved the development of domain specific skills and fostered the development of self-regulation, which is a promising step towards improving the efficiency of training and continuous learning.

Appendix I; Example of a Learning task Worksheet



ACS - Student Manual Versie

OEFENING C2J

DOELSTELLINGEN VAN DE OEFENING

- Inbound verkeer mergen en streamen en onderling 5 NM creëren (vectoring, speedcontrol)
- Eventuele conflicten met outbound/overvliegend verkeer zo veel mogelijk oplossen met level management

AFSPRAKEN EN OVERIGE INFORMATIE

- Uiterlijk 10 minuten prior ETO boundary moet de BEM worden gecoördineerd met BREMEN sector 1 of 2.
- De TCM hoeft niet meer te worden gecoördineerd met APP.

VERKEERSCOMPLEXITEIT

🟪 Regio
🟧 Transit
🟦 Outbound
🟨 inbound

OEFENING GEGEVENS

Gebruikte runway	EHFN06 EHGD05
Controllers / Pilots	1 / 2
Weertemplate	4
Bovenwind	Ja
EHFN inbound/outbound	7 / 5
overflights	2
EHGD inbound / outbound	2 / 0
verkeer van EHGD naar EHFN	N.v.t.

COMPETENTIE TRAINING

Traffic Flow	+		Aandachtverdeling	++
Communicatie	+		Mentaal beeld vormen	++
Coördinatie	++		Planning	++
Labelmanagement	+		Besluitvaardigheid	-
Waarneming	++		Omgaan met werkdruk	-
			Samenwerking	-
			sequencen	++
		performance verschil	inbound:	++
		performance verschil	outbound:	-

Type conflicten	Categorie 1: eenvoudige conflicten (Oplossen met verticale separatie).
Unusual Situations	Niet van toepassing in deze stap

Learning task metadata

VOORBEREIDING (VOOR DE OEFENINGSBRIEFING INVULLEN)

Aan welke persoonlijke aandachtspunten wil je gaan werken tijdens de oefening?

Hoe ga je daar in de komende oefening aan werken?

Wat verwacht je hierin van de coach? (Denk aan: Direct verbeteren / ingrijpen - Extra uitleggen / voordoen)

Regulation prompt prior to task

EVALUATIE (VOOR DE OEFENINGS-DE-BRIEFING INVULLEN)

Hoe heb je de aandachtspunten voor deze oefening aangepakt? Was de aanpak zinvol?

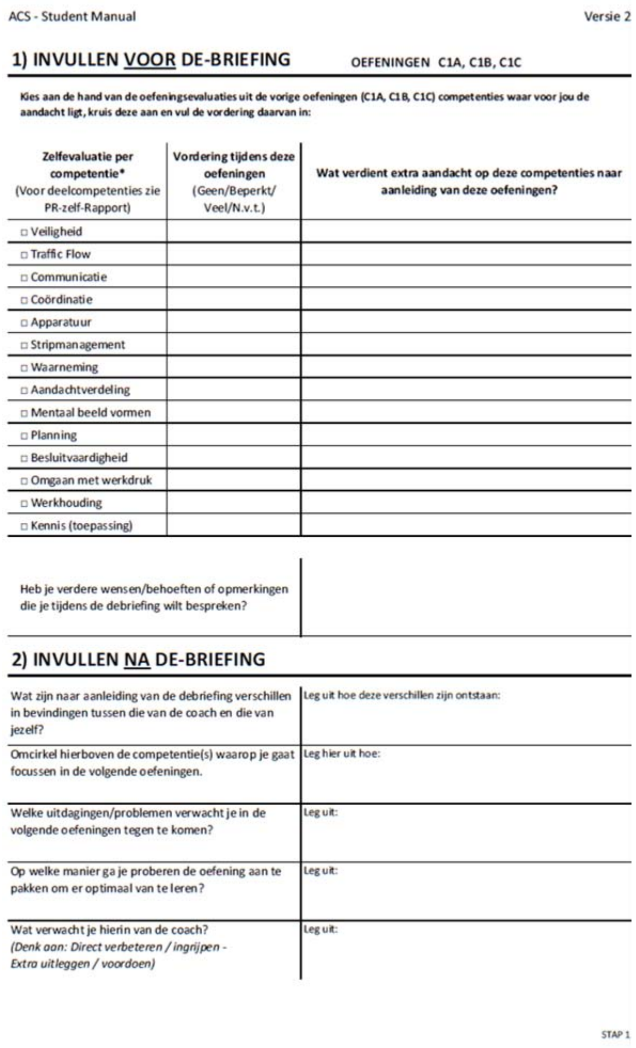
Noteer punten die goed zijn gegaan tijdens deze oefening:

Noteer punten die minder goed zijn gegaan tijdens deze oefening:

Regulation prompt, after task

STA

Appendix II; Example of a Learning task Self-report



ACS - Student Manual Versie 2

1) INVULLEN VOOR DE-BRIEFING OEFENINGEN C1A, C1B, C1C

Kies aan de hand van de oefeningsevaluaties uit de vorige oefeningen (C1A, C1B, C1C) competenties waar voor jou de aandacht ligt, kruis deze aan en vul de vordering daarvan in:

Zelfevaluatie per competentie* (Voor deelcompetenties zie PR-zelf-Rapport)	**Vordering tijdens deze oefeningen** (Geen/Beperkt/ Veel/N.v.t.)	**Wat verdient extra aandacht op deze competenties naar aanleiding van deze oefeningen?**
☐ Veiligheid		
☐ Traffic Flow		
☐ Communicatie		
☐ Coördinatie		
☐ Apparatuur		
☐ Stripmanagement		
☐ Waarneming		
☐ Aandachtverdeling		
☐ Mentaal beeld vormen		
☐ Planning		
☐ Besluitvaardigheid		
☐ Omgaan met werkdruk		
☐ Werkhouding		
☐ Kennis (toepassing)		

Heb je verdere wensen/behoeften of opmerkingen die je tijdens de debriefing wilt bespreken?	

2) INVULLEN NA DE-BRIEFING

Wat zijn naar aanleiding van de debriefing verschillen in bevindingen tussen die van de coach en die van jezelf?	Leg uit hoe deze verschillen zijn ontstaan:
Omcirkel hierboven de competentie(s) waarop je gaat focussen in de volgende oefeningen.	Leg hier uit hoe:
Welke uitdagingen/problemen verwacht je in de volgende oefeningen tegen te komen?	Leg uit:
Op welke manier ga je proberen de oefening aan te pakken om er optimaal van te leren?	Leg uit:
Wat verwacht je hierin van de coach? *(Denk aan: Direct verbeteren / ingrijpen - Extra uitleggen / voordoen)*	Leg uit:

STAP 1

Evaluation of the progress on the 14 ATC main competences

Preparation for learning task debriefing

Appendix III; Dutch STPQ

Beste LVNL kandidaat,

Bedankt dat je mee doet aan dit onderzoek van het Centre For Learning Sciences and Technologies.

De volgende stellingen gaan over de taak die je morgen gaat doen en waar je vandaag op voorbereid bent.

*Denk dus bij het woord **taak** aan wat je morgen gaat doen.*

Vul altijd bij elke stelling één antwoord in.

Beantwoord in hoeverre een stelling voor je van toepassing is (van zeer oneens tot zeer eens).

Bedenk dat er geen goede of verkeerde antwoorden zijn.

Het is belangrijk dat je zo precies als mogelijk voor jezelf een inschatting maakt.

Lever het vragenformulier in, nadat je alle vragen hebt beantwoord.

De vragenlijst zal worden geanonimiseerd, toch vragen we voor de administratie je naam in te vullen

De resultaten van deze vragenlijst zullen *uitsluitend* voor wetenschappelijke doeleinden worden gebruikt en zullen op *geen enkele wijze* invloed hebben op welke beoordeling bij LVNL dan ook.

NAAM:…………………………………………………………………

Geslacht: M / V (doorhalen wat niet van toepassing is)

Leeftijd:………………………………………………………….Jaar

		zeer oneens	oneens	Oneens / eens	eens	zeer eens
1	Ik ben er van overtuigd dat ik de basisvaardigheden die deze taak traint, zal leren.	○	○	○	○	○
2	De moeilijkheid van deze taak en mijn vaardigheden in acht nemend, denk ik dat ik deze taak aankan.	○	○	○	○	○
3	In een taak als deze houd ik van uitdagingen zodat ik nieuwe dingen kan leren.	○	○	○	○	○
4	De benodigde persoonlijke vereisten voor deze taak zijn duidelijk voor mij.	○	○	○	○	○
5	Ik weet niet zeker welke leerstrategieën voor deze taak het beste zijn.	○	○	○	○	○
6	Ik baal omdat de meeste anderen beter zullen zijn in deze taak dan ik.	○	○	○	○	○
7	Het goed uitvoeren van deze taak is belangrijk voor mij.	○	○	○	○	○
8	Ik heb voldoende tijd om deze taak goed te volbrengen.	○	○	○	○	○
9	Ik heb er plezier in om van deze taak te leren.	○	○	○	○	○
10	Een goede beoordeling voor deze taak is het meest belangrijke op dit moment.	○	○	○	○	○
11	Ik ben er van overtuigd dat ik een goede beoordeling ga halen voor deze taak.	○	○	○	○	○
12	Ik ben er van overtuigd dat ik de lastigste situaties in deze taak aankan.	○	○	○	○	○
13	Noch de pilots in deze taak, noch de omgeving zal mij belemmeren in mijn taakuitvoering.	○	○	○	○	○
14	Ik ben tevreden met mijn resultaten in oefeningen tot nu toe.	○	○	○	○	○

15	De strategieën die ik in deze taak moet toepassen zijn moeilijk om te bepalen.	o	o	o	o	o
16	Ik denk dat ik een betere beoordeling voor deze taak ga halen dan de meeste anderen in mijn groep.	o	o	o	o	o
17	Ik ben er zeker van dat ik momenteel de vaardigheden leer die ik nodig heb voor deze taak.	o	o	o	o	o
18	Ik weet welke strategieën het beste passen bij wat deze taak vereist.	o	o	o	o	o
19	Ik verwacht goed te presteren in deze taak.	o	o	o	o	o
20	Ik ben geïnteresseerd in de te gebruiken kennis van deze taak.	o	o	o	o	o

Zijn alle vragen ingevuld? Bedankt voor het meedoen!

Factor: Self-efficacy for task performance (α = .826; 6 items)
Items 2, 11, 12, 14, 16, and 19

Factor: Self-efficacy for learning (α = .731; 7 items)
Items 1, 3, 4, (-6), 8, 9, and 13

Factor: Task value (α = .617; 5 items)
Items 7, (-10), 17, 18, and 20

Appendix IV; Dutch PRO-SDL

Beste student,

Bedankt dat je mee doet aan dit onderzoek van het Centre For Learning Sciences and Technologies.

- De vragenlijst is geheel anoniem.
- De stellingen gaan over recentelijke leerervaringen in je studie.
- Indien er over “oefeningen” wordt gesproken, denk dan aan “opdrachten” in (werk)colleges
- Vul altijd bij elke stelling één antwoord in.
- Beantwoord in hoeverre een stelling voor je van toepassing is (van *zeer oneens* tot *zeer eens*).
- Bedenk dat er geen goede of verkeerde antwoorden zijn.
- Het is belangrijk dat je zo precies mogelijk voor jezelf een inschatting maakt.
- De antwoorden zullen op geen enkele manier invloed hebben op een beoordeling.

Geslacht: M / V (doorhalen wat niet van toepassing is)

Leeftijd:………………jaar

		zeer oneens	oneens	oneens /eens	eens	zeer eens
1	Ik ben er van overtuigd dat ik mij constant kan motiveren.	o	o	o	o	o
2	Ik doe regelmatig extra werk voor een oefening, puur uit interesse.	o	o	o	o	o
3	Ik zie geen verband tussen het werk dat ik in de oefeningen doe en mijn persoonlijke doelen en interesses.	o	o	o	o	o
4	Als mijn prestaties in een oefening achterblijven bij mijn eigen verwachtingen dan doe ik er zelf alles aan om mijn prestaties te verbeteren.	o	o	o	o	o
5	Ik neem altijd zelf de verantwoording voor mijn eigen leren.	o	o	o	o	o
6	Ik heb problemen met mezelf te motiveren om te leren.	o	o	o	o	o

7	Ik ben er van overtuigd dat ik in staat ben mijn eigen leerdoelen te prioriteren.	o	o	o	o	o
8	Ik bereid me voor op oefeningen omdat ik dat wil, niet omdat ik dat moet.	o	o	o	o	o
9	Ik neem zelf het initiatief om nieuwe dingen te leren en wacht niet op een aanmoediging van een instructeur.	o	o	o	o	o
10	Ik gebruik vaak materialen die ik zelf heb gevonden om het leren te ondersteunen.	o	o	o	o	o
11	Voor de meeste oefeningen weet ik niet waarom ik ze moet doen.	o	o	o	o	o
12	Ik ben overtuigd van mezelf dat ik in staat ben om mijn eigen leren te sturen.	o	o	o	o	o
13	Als de instructeur mij vraagt zelf een leerplanning te maken, dan lukt me dat niet.	o	o	o	o	o
14	Het meeste van het werk dat ik in de oefeningen doe vind ik plezierig of lijkt mij relevant gezien mijn opleiding die ik volg.	o	o	o	o	o
15	Zelfs als een bepaalde oefening voorbij is dan blijf ik investeren in leren over dat onderwerp.	o	o	o	o	o
16	De belangrijkste reden om te voldoen aan de eisen van een oefening is om de beoordeling te behalen die men van mij verwacht.	o	o	o	o	o
17	Ik verzamel vaak nog aanvullende informatie over interessante onderwerpen, zelfs als een module daarover al is afgelopen.	o	o	o	o	o
18	De belangrijkste reden voor mij om een module te volgen is om te voorkomen dat ik me schuldig zou voelen over het behalen van een slechte beoordeling.	o	o	o	o	o

19	Ik ben succesvol in het prioriteren van mijn eigen leerdoelen.	○	○	○	○	○
20	De meeste activiteiten die ik doe in het kader van mijn opleiding zijn niet persoonlijk bruikbaar en zijn niet interessant.	○	○	○	○	○
21	Ik ben onzeker als het gaat om het nemen van persoonlijke verantwoordelijk over mijn eigen leren.	○	○	○	○	○
22	Ik ben er onzeker over of ik in staat ben om zelf externe informatiebronnen te vinden voor mijn oefeningen.	○	○	○	○	○
23	Ik organiseer mijn studietijd altijd effectief.	○	○	○	○	○
24	Ik heb er niet veel vertrouwen in dat ik mijn studieplannen zelfstandig kan uitvoeren.	○	○	○	○	○
25	Ik vertrouw altijd op de instructeur om te laten vertellen wat ik moet doen om een vak goed af te ronden.	○	○	○	○	○

Zijn alle vragen ingevuld? Bedankt voor het meedoen!

Factor: Responsibility for learning (α = .788)
Items 1, 4, 5, (-6), 7, 12, 19, and 23

Factor: Taking initiative (α = .693)
Items 2, 9, 15, and 17

CHAPTER 6

General Discussion

The studies in this dissertation took a close look at how air traffic control (ATC) training can focus on both successfully teaching complex ATC skills and self-regulation skills, preparing future air traffic controllers for working in a dynamic environment which demands continuous learning. Therefore, on the one hand, this dissertation elaborates on training ATC-specific competences, particularly those related to *visual expertise*. On the other hand, it focuses on *regulation skills* for successful training and future learning in the ATC domain. The final aim is to integrate the training of ATC-skills and regulation skills in one training program.

Main Findings and Conclusions

Task performance in ATC relies heavily on visual search and visual information processing. The complexity of the domain makes it likely that there are multiple acceptable solutions for a single air traffic situation while the underlying strategies could be similar, or, in contrast, different strategies can lead to similar or equivalent solutions (Fields, 2006; Medin et al., 2006). While it is known that experts are capable of using visual strategies that allow for fast and correct selection of required screen information (cf. Gegenfurtner, Siewiorek, Lehtinen, & Säljö, in press; Reingold & Sheridan, 2011), research focusing on the training of visual problem-solving skills has been limited (Jarodzka, Boshuizen, & Kirschner, 2012; Jarodzka, Van Gog, Dorr, Scheiter, & Gerjets, 2013). To design training on visual problem-solving skills in complex cognitive domains (e.g., ATC, power plant control), it is required to map out what visual strategies set experts apart from intermediates, what visual strategies set intermediates apart from novices, and how these are related to solution similarity. Therefore the first question to answer in this dissertation was: What visual strategies do experts, intermediates and novices use in the field of ATC?

Eye-tracking data (Chapter 2) provided insight into visual strategies that novices, intermediates, and experts use when solving ATC tasks and if these strategies led to similar solutions. To reuse eye-tracking recordings of experts as models for teaching (i.e., eye-movement modeling examples or EMMEs), it must be checked how many different solutions experts' strategies provide. Therefore, performance was analyzed in terms of similarity of solutions. First, three different strategies were defined: Means-end analysis, information reduction, and chunking. The results revealed that the groups with higher expertise (i.e., intermediates and experts) used the information reduction strategy more often than novices. Chunking was mostly found in experts, while the use of means-end analysis was only found in novices. Second, an increase in solution similarity was found in the groups with higher expertise. Hence, the study clearly demonstrated the assumed relation between expertise and visual strategies and between expertise and solution similarity. These findings can help to design instruction using EMMEs and teach students how to use different visual strategies when solving ATC tasks. They provide indications for which strategies can best be used to train for each level of expertise, and how EMMEs should differ for groups with different levels of expertise. Recent studies by Jarodzka and her colleagues (e.g., Van Gog, Jarodzka, Scheiter, Gerjets, & Paas, 2009) successfully applied eye-movement recordings and voice recordings from models who explained their actions – while carrying them out – in a pedagogically adequate way so as to train novices to recognize different species of fish based on their fin-movements (Jarodzka et al., 2013) and to diagnose epileptic seizures in infants (Jarodzka et al., 2012). Such EMMEs, however, have not been applied in ATC. Hence, the conclusions of this study contribute to the existing literature on assessing expertise differences for visual problem-solving skills (e.g., Gegenfurtner et al., 2011, in press; Reingold & Sheridan, 2011) and on training these skills (Jarodzka et al., 2012, 2013) by providing insight in strategy-use between different levels of expertise in a cognitive complex domain, and by suggesting implications for training visual skills in this domain by means of EMMEs. Although the solution similarity of expert strategies is relatively high, they might still be somewhat different and lead to slightly different solutions. Hence, it is important that EMMEs reflect the divergence in visual problem-solving strategies as applied by experts (Van Merriënboer & Kirschner, 2013).

Students must not only learn to master the ATC-skills as they are necessary at the moment of their training (e.g., visual problem-solving; Oprins, Burggraaff, & Van Weerdenburg, 2006), but they must also be prepared for changes in working procedures and conditions due to technological developments of the tools they use, alterations in the rules governing air traffic and its control, and increasing air traffic in general (Eurocontrol Statfor, 2010).

These changes require professionals who are able to continue learning throughout their careers to maintain competency, despite the rapidly changing world around them (Bolhuis, 2003; Jha, Bisantz, Parasuraman, & Drury, 2012; Van de Merwe, Oprins, Erikkson, & Van der Plaat, 2012; Van Merriënboer, Kirschner, Paas, Sloep, & Caniëls, 2009). Regulation skills increase the awareness of experts regarding shortcomings in their performance, which can motivate them to address these shortcomings in training programs or by deliberate practice (Eva & Regehr, 2005; 2008). Therefore, in training prospective air traffic controllers, specific attention should be paid to the development of regulation skills that prepare them for continuous learning (Bolhuis, 2003; Candy, 1991). This dissertation further focused on this issue by answering the following questions: Which regulation skills are important for ATC students according to the different stakeholders in the training process? What are the requirements for a learning environment that is intended to integrate the development of domain-specific and self-regulation in a cognitively complex domain such as ATC? And: what is the effect of integrating training of self-regulation skills and ATC-skills on the development of self-regulation and domain-specific performance?

A focus-group study (Chapter 3) was conducted to gain insight in the skills that are important for students for successful learning in ATC, and in how cognitions about these skills differ among three groups of stakeholders (i.e., training designers, trainers/coaches, trainees). Results showed that *setting learning goals* and *identifying human and material resources* (i.e., self-directed learning skills or SDL) are of main importance for successful training in ATC, followed by *self-efficacy*, *learner engagement*, and *self-regulated learning* (SRL) skills. Cognitions about successful learning turned out to be different between the three groups of stakeholders. Training designers and trainers/coaches stressed the importance of learners' insight in the learning opportunities provided by learning tasks. Students, in contrast, often thought that optimal performance on the learning tasks rather than learning from them is the main goal of training. These findings have clear implications for instruction: Training design should meet requirements for the training of SDL skills, self-efficacy, SRL skills, and learner engagement. This is in line with earlier research showing positive relations between students' self-regulation and learning outcomes (e.g., Boekaerts & Cascallar, 2006; Loyens, Magda, & Rikers, 2008; Pintrich &

De Groot, 1990; Zimmerman, 1990). Students must be given a certain degree of responsibility over setting their own learning goals and delineating their own learning trajectories by selecting their own learning tasks based upon SRL skills such as self-assessment (Kicken, Brand-Gruwel, & Van Merriënboer, 2008). They can only select suitable learning tasks if they understand the learning opportunities provided by these tasks (cf. Taminiau et al., 2013), which will also reduce the distinction between the students' aim of a learning task (i.e., high performance) and the training designers and trainers/coaches aim of a learning task (i.e., optimal learning). A new design of an ATC training environment should therefore foster the development of self-regulation (i.e., SDL skills, SRL skills, self-efficacy) by integrating the use and learning of these skills with the training of ATC-specific competences.

The integrated training of self-regulation skills and domain-specific skills is not self-evident. This deals with the paradox that a system in which students can regulate their own learning (i.e., a learner-controlled system) requires students to have already developed these skills (Corbalan, Van Merriënboer, & Kicken, 2010). Based on theoretical considerations, Chapter 4 proposes using a shared-controlled system to solve this so-called SDL paradox. The need for adaptability in such training system requires that responsibility over learning task selection is fully adapted to individual learning needs: As Students develop their SRL skills, they are given increasingly more control over the selection of learning tasks. In that way only, students can become gradually involved in learning task selection which fosters their SDL skills, SRL skills and self-efficacy (Jossberger, Brand-Gruwel, Boshuizen, & Van de Wiel, 2010).

Earlier studies showed several possibilities for designing for dynamic task selection in training. For example, Corbalan, Kester, and Van Merriënboer (2008) used pre-selection of learning tasks with an appropriate complexity level. The remaining freedom of students' choice resulted in higher motivation (i.e., task involvement) than when no freedom in choice was given. In ATC, Salden, Paas, and Van Merriënboer (2006) demonstrated the positive effects of personalized task selection on the efficiency of training. However, in order to increase the effectiveness of training (i.e., performance) students should also learn which factors are important to base their task-selection on (Corbalan, Kester, & Van Merriënboer, 2009b).

To provide insight in the advantages and disadvantages of shared-controlled training systems, they were compared with two other types of adaptive systems (i.e., learner-controlled and system-controlled) as well as non-adaptive systems. The analysis showed that only a shared-controlled adaptive training system meets all requirements for the integrated training of self-regulation skills and domain-specific skills. It is the only system that ensures that the final attainment level is reached by all students, that training is efficient in terms of time and number of necessary learning tasks, that self-regulation skills can be trained in combination with ATC-skills, and that progress of students is carefully monitored. The analysis also provided insight in the necessary elements of a learning system that integrates instruction in self-regulation skills and domain-specific skills. A *database of learning tasks* must be available in the system so that students and/or the system can select suitable learning tasks. *Metadata of the tasks* must be available to enable students and/or the system to match learning opportunities provided by a particular learning task with individual learning needs. The need for a *development portfolio* is also demonstrated. Such a portfolio is necessary to support the process of defining learning needs and to match these needs with learning tasks available in the database. Finally, a *coaching protocol* may help coaches to fulfill their role in the training system, that is, to guide students in their process of defining learning needs and selecting learning tasks.

Characteristics of a shared-control adaptive training system were used in a final empirical study (Chapter 5) to answer the question of what the effect of shared control is on students' SRL skills, SDL skills, self-efficacy, and domain-specific performance. To answer this question, an existing training system focusing on solely ATC-specific competences was compared with an integrated training system with the aim to develop both students' self-regulation skills and ATC-specific competences. Although the shared control implemented in the new system did not allow students to fully independently select their own learning tasks, its results were promising. As a precursor of a fully integrated development portfolio, students received worksheets for each learning task containing metadata and regulation prompts. The regulation prompts were presented both before the task (i.e., preflective) and after the task (i.e., reflective) to foster the development of SRL skills, SDL skills and self-efficacy and to stimulate learner engagement. Results showed that the integrated training program led to an increase in students' SRL skills and self-efficacy while ATC-skills improved at the same time, compared to the original non-integrated system. The increase in SDL skills, however, lagged behind. The study confirmed earlier research that self-regulation is important for successful learning in complex domains (e.g., Eva & Regehr, 2005, 2008). Moreover, the study supported the idea of Jossberger et al. (2010) that integrating the development of self-regulation skills with domain-specific skills can be successful. From these results it can be concluded that students' regulation of their learning can be fostered by allowing them to do so as integrated part of their domain-specific training. The results also suggested that students will probably only develop SDL skills when at a certain point in the training program they are given full control over the selection of learning tasks. This is in line with Kicken, Brand-Gruwel, Van Merriënboer, and Slot (2009a), who found that for improving students' SDL skills their actual selection of new learning tasks is a necessary requirement.

Implications

Instructional guidelines can be obtained from both the conclusions on visual problem-solving skills and the integrated training of self-regulation skills and domain-specific skills. These guidelines aim at a better preparation of ATC students for their future dynamic working environment.

Instruction for novices should make clear to them which visual information is needed to work forward towards the goal instead of backwards from the goal. In that way, the learner could be shown how decisions are made without focusing on the target (e.g., the fixed location of the general destination point). Instructional materials must show novices which information is relevant for problem-solving and where this information is located in the complex visual representation (e.g., through EMMEs). Instruction for intermediates should take into account their tendency to focus on irrelevant information resulting in a relatively high cognitive load. Therefore, EMMEs should train them to focus on the relevant information required to take safe decisions and so reduce their visual search. In addition, instruction should focus on prototypical situations for which experience is required for using the chunking strategy (e.g., Gobet & Simon, 1998). In this way, intermediates learn how to recognize the most relevant information within a group of objects and, then which information is crucial to rely on in a certain situation. For experts, EMMEs could be used, on the one hand, to train them in working with new technologies or new regulations when other information elements must be observed in perceptual tasks (Gegenfurtner et al., in press). In such situations, EMMEs could be helpful in the same way as they are helpful for intermediates. On the other hand, eye-movement recordings of peers or even from themselves could help foster reflection on the use of their own visual strategies and so contribute to a process of deliberate practice.

Cognitive theories were used to predict the findings on visual processes. For some visual processes these theories turned out to be applicable. For other visual processes these theories turned out to be too limited. More insight in the background of visual problem-solving is required and cognitive theories should be extended towards visual cognitive (i.e., perceptual) theories. Such theories should further explain visual processes that experts use to work in a goal-oriented fashion. This can help to further develop instruction for training experts' abilities (i.e., to see all small but relevant details and to chunk incoming information.)

The findings on integrated training of self-regulation skills and domain-specific skills also have implications for theory and practice. To integrate training of self-regulation and domain-specific skills, an adaptive training system must apply shared control over learning task selection. This requires a database of labeled training-tasks with elaborate metadata in the label. These metadata should contain detailed information about details such as task difficulty, training possibilities for particular competences, and minimally required prior knowledge to enable matching individual learning needs to learning tasks with the best learning opportunities.

Limitations and Suggestions for Future Research

The studies reported in this dissertation have limitations following from methodological and practical issues. The fact that all studies took place in the ATC-domain strengthens the ecological validity but limits the generalizability of the findings. It is probable that there are similarities with training in other safety-related domains where optimal human action is required (e.g., power plant control), but no validation study was conducted to generalize the results to other domains. It is therefore important to replicate studies in other cognitively complex domains.

The empirical studies had limited numbers of participants. This, however, is common in expertise studies because the number of available experts in a domain is typically limited and the use of experts is expensive (Gegenfurtner et al., 2011). The number of participants in the training experiments was also limited; yet, actually everyone available at Air Traffic Control the Netherlands and who met the requirements for participating in the study, during the four years of data collection, took part in the reported studies.

Although the studies were conducted using different research methods, the eye-tracking and cued retrospective reporting yielded large amounts of data that had to be processed manually. To improve the reliability of the data, more triangulation of methods could have been used to ensure the correct interpretation of outcomes.

The studies took place in the actual work environment of ATC, causing further limitations. In the time span between the original training program and the integrated training program, the simulated airspace used for the learning tasks had to be updated. This update affected the ATC assignments and course assignments which were used to determine the performance and SRL skills. Obviously, everything was done to keep performance measures similar and comparable between groups: numbers of conflicts ahead, number of crossers, and sort of traffic situation. Moreover, for statistical analysis the increase in performance was used rather than the final end scores, which will have eliminated most of the possible influences of the changed environment. Only future studies with higher experimental control (e.g., in a lab-based environment) can prevent such limitations. But also for this reason our finding must be interpreted with care.

Finally, the finding that in the intervention study SDL skill development lagged behind can be related to not giving students full control over the selection of learning tasks, but also to the length of the intervention. SDL skills might need more time to develop than was available in the integrated training program. In addition, the development of SDL skills was only measured by means of self-reports (i.e., PRO-SDL questionnaire). The use of self-reports is a limitation as participants might not have observed their own change in learning behavior. Future research should use more direct measures of SDL skills to better map out their development.

In sum, for training purposes, future research should elaborate on perceptual theories and on the design and use of EMMEs for training visual problem-solving skills in complex cognitive working environments. Future research on training programs that integrate development of self-regulation skills and domain-specific skills should also study the development of SDL skills in training situations that (a) provide students more control over task selection, and (b) extend over a longer time period. More triangulation of methods and higher experimental control will also be useful contributions to the further study of training programs that integrate the development of self-regulation skills and self-efficacy with domain-specific skills.

Final Conclusion

The main aim of this dissertation was to gain a better understanding of the visual skills involved in ATC and to develop instructional guidelines that may help to better prepare ATC students for future learning. The studies in this dissertation mapped out optimal strategies for visual problem-solving and deficiencies of novices and intermediates in visual problem-solving, which resulted in practical implications for training visual problem-solving skills. Insight was also obtained in regulation-skills required for successful learning in ATC, and possible training systems for integrating the development of students' self-regulation skills with ATC-skills were compared. An integrated training program to train self-regulation in ATC training has been tested successfully. An important step forward has been made in the development of guidelines for training complex cognitive skills in a visual domain. These guidelines help to train air traffic controllers successfully by extending the training methods for both visual problem-solving and self-regulated learning.

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SUMMARY

Air traffic controllers must adapt to and act upon continuing changes in a highly advanced technological, complex, and visually oriented work environment. Therefore, air traffic control (ATC) students must not only learn the complex ATC skills as they are required at the moment of their training, but must also learn to adapt and develop competences to be prepared for future changes. Such changes may concern working procedures, new technologies, rules of governing and controlling air traffic, and the increasing rate of air traffic. Present training programs for air traffic controllers do not optimally take future changes into account, and students are not specifically prepared for future learning because these programs pay no attention to the development of self-directed and self-regulated learning skills.

The main aim of this dissertation is to gain a better understanding of the visual problem-solving skills involved in ATC and to develop instructional guidelines that help ATC students to better prepare for future learning. Chapter 1 introduces the aspects that make the ATC domain complex and addresses the main research questions that will be answered in this dissertation. This domain requires continuous human performance that ensures optimal safety, but also considers efficiency. Working on this fine line between safety and efficiency makes the work of an air traffic controller a sustained effort to find optimal solutions. Moreover, ATC is primarily a perceptual task where task performance heavily relies on visual search (i.e., accurate identification of important objects) and visual information interpretation. While there is a fair amount of research on expert-novice differences, the number of studies which include intermediates is limited (cf. Gegenfurtner, Lehtinen, & Säljö, 2011). To improve instruction, it is important to determine which visual strategies are used in visual problem-solving at different levels of expertise, including intermediates. Therefore the first study in this dissertation addressed the question: *Which visual strategies are used in ATC by experts, intermediates and novices?*

Next to the visual complexity of ATC, the domain is evolving at an increasing rate. Air traffic controllers are regularly confronted with major changes in the technologies they use and the regulations they have to follow. Therefore, air traffic controllers and ATC students not only need to master domain-specific ATC competencies but also need to be able to react adequately to changes in their work to maintain their expertise across their working lifetime. To train air traffic controllers so that they can keep up with their unremittingly changing work environment, instruction in ATC must include the training of regulation skills. Therefore, the second question in this dissertation is: *Which regulation skills are important for ATC students, according to the different stakeholders in the training process?* As the aim is to train students' regulation skills as an integrated part of their ATC training also the following question has to be answered: *What are the requirements for a learning environment intended to* integrate *the development of domain-specific ATC skills and self-regulation skills, in a cognitively complex domain such as ATC?* To verify the plausibility of an integrated training of self-regulation skills in ATC training, the fourth and final question is: *What is the effect of an integrated training of self-regulation skills on students' self-regulation and on their domain-specific performance?*

Four studies were conducted to answer the four research questions. Chapter 2 describes a study on ATC-specific complex competences, particularly those related to visual expertise; Chapters 3-5 focus on self-directed and self-regulated learning skills and the possibilities to embed instruction of these skills in training and so prepare students for future learning. Chapter 6 summarizes the main findings presented in Chapters 2 through 5 and answers the research questions introduced in Chapter 1. In addition, the findings are discussed in terms of conclusions and limitations, implications for instruction, and directions for future research.

Chapter 2 describes a study to gain insight in the visual problem-solving strategies of experts, intermediates, and novices. Research revealed that people with different levels of expertise use different strategies when solving complex visual problems (Gegenfurtner et al., 2011; Reingold & Sheridan, 2011). Although visual skills are of high importance in many domains (e.g., health sciences, transport, aviation) there is limited experience in actively teaching these skills to individuals (Jarodzka, Scheiter, Gerjets, & Van Gog, 2010). In order to design instruction to foster visual expertise in the domain of ATC, it is important to understand the strategies that experts, intermediates and novices use to process complex visual information from a radar screen. How do they determine what objects are relevant to retrieve information from (e.g., aircraft, speeds, flight levels, etc.)? How do they make decisions based on that information? This study focused on three visual problem-solving strategies: First, means-end analysis as an inefficient novice strategy in which there is a permanent focus on the destination of aircraft; second, the information-reduction strategy that optimizes the amount of processed information by separating task-irrelevant from task-relevant information, and third, the chunking strategy that allows to combine elements so they can be treated in working memory as one information element. The study aims at determining strategy use by experts, intermediates and novices in the field of ATC by means of eye-tracking, and investigates the moderating effect of task difficulty on the differences between these groups. Furthermore, in ATC the number of possible solutions is restricted by safety rules and the need to deal with air traffic in an efficient way. Yet, there are many degrees of freedom in finding these solutions (e.g., changing speed, height, or direction). For the design of optimal instruction, insight is required in the number of plausible solutions when solving complex problems (Medin et al., 2006). The expectation is that experts have the ability to quickly recognize a broad range of problem situations that allows them to bring in optimal solutions. Because most of these solutions are optimal, they can be expected to be relatively similar. To gain insight in differences between levels of expertise, this study takes into account solution similarity within and between groups of expertise.

Eye-tracking data were recorded from 31 participants (10 experts, 9 intermediates, and 12 novices). Participants worked on nine ATC tasks while their eye-movements were recorded. For each task, the assignment was to give an optimal solution for a static traffic situation by naming the optimal order of arrival of the aircraft as quickly as possible. Analysis of the data clearly supported the hypothesis that experts, intermediates and novices use different visual problem-solving strategies. First, there was more effective information reduction for higher levels of expertise. Second, experts showed more chunking of related elements than intermediates and novices. Third, experts seem to use a working-forward strategy instead of means-end analysis. These findings add to earlier findings by Jarodzka et al. (2010) and Medin, Lynch, Coley, and Atran (1997), showing that higher expertise is related to higher similarity in reached solutions. These findings have important implications for instruction, because they may help create eye-movement modeling examples (i.e., reuse of experts' eye-movement recordings) for the teaching of visual problem-solving strategies in complex visual domains.

The focus group study described in Chapter 3 aimed at determining and ordering learner characteristics required to involve students in a successful ATC learning process. Therefore, this study focused on three specific questions: (1) Which learner characteristics determine successful learning in ATC according to the different stakeholders (i.e., designers, trainers/coaches, and students)? (2) What are the similarities and differences between the three groups of stakeholders with respect to the importance of learner characteristics? (3) What are the similarities and differences between the three groups of stakeholders with respect to their rationales for ranking particular characteristics as being important or not?

Six instructional designers, seven trainers/coaches, and seven students from the Dutch ATC-training volunteered for participation in this study. The participants were divided into three homogeneous focus groups: A designer group, a trainer/coach group, and a student group. They carried out a focus-group preparation task one week prior to the focus groups, in which they were asked to indicate factors for successful learning based on a critical incident from their own experience. The results of the preparation tasks were given to the interviewer before the focus group meetings. All meetings were chaired by the same person who gave a general introduction to the topic and explained the discussion rules. Each meeting lasted approximately two hours and all meetings were audio-recorded and transcribed. A quantitative analysis yielded average rankings for characteristics of successful learning according to the stakeholders, while a qualitative analysis shed light on why the characteristics for successful learning in ATC are considered important by the different stakeholders. There was a high overall agreement between the stakeholder groups, as can be concluded from a significant correlation between the three rankings, but differences between the rankings were also found. From the agreement between stakeholders it is concluded that the ability to set learning goals and to identify human and material resources are of great importance for successful learning. From the differences between stakeholders it is concluded that learners do not automatically think about their learning needs and goals while carrying out learning tasks, and they seem to focus more on performing the tasks than on learning from those tasks. Finally, in Chapter 3, implications for instruction are discussed to prevent stakeholders' diverging cognitions about successful training. A new design of an ATC training environment should foster development of self-regulation skills (i.e., SDL skills, SRL skills, self-efficacy) by integrating practice on these skills in the training of ATC-specific competences. This is expected to give students a certain degree of responsibility over their own learning and help them to better understand the learning opportunities brought in by learning tasks.

The design of a learning environment intended to integrate the development of domain-specific skills and self-regulation skills reveals a paradox: A system that gives students the opportunity to regulate their own learning expects them to have already developed regulation skills (Corbalan, Van Merriënboer, & Kicken, 2010). To solve this paradox, Chapter 4 presents an adaptive training system in which system and learner share control over learning-task selection, so that students can be supported in their development of self-regulation skills and, specifically, self-directed learning skills. The chapter discusses the necessary requirements for a learning environment integrating the development of domain-specific and self-regulation skills in a cognitively complex domain such as ATC. A distinction is made between adaptive training systems (i.e., systems in which each student follows an individual learning path) and non-adaptive training systems (i.e., systems where each student follows a learning path designed for the "average" learner), and between three types of control in adaptive systems. First, system-controlled training systems are discussed; here, the learning tasks are chosen by the system, for example a coach or a computer program. Second, learner-controlled systems are discussed; here, the responsibility over learning-task selection fully relies on the student. Third, shared-controlled systems are discussed; here, the responsibility over learning-task selection gradually moves from the system towards the learner as students' self-regulation skills develop. It is argued that only shared control over task selection can meet the requirements for integrated training of students' regulation skills in a complex cognitive domain. Such systems ensure a high final attainment level (i.e., the training is effective), a high training efficiency (e.g., training suits the individual learning needs), a continuous monitoring of learners' progress, and a gradual and guided development of regulation skills. Thus, shared-controlled systems can offer a solution for the paradox. The elements of such shared-controlled, adaptive training systems are described. These elements are a: (1) database with learning tasks coupled with metadata on the basis of which the tasks can be selected; (2) development portfolio for gaining insight into competence development, defining learning needs, and setting learning goals, and (3) coaching protocol to adjust the level of guidance to the level of the students' regulation skills.

Chapter 5 describes a study on the effect of an integrated training on students' self-regulation and domain-specific performance in real ATC-training practice. For this study the Area Control Surveillance course was redesigned at Air Traffic Control the Netherlands. The redesign made it possible to develop students' regulation skills while training ATC competences (i.e., integrated condition). In this integrated condition, regulation prompts were embedded to prepare students for learning-task selection, and a development portfolio including learning-task worksheets was provided to the students. The learning-task worksheets comprised the tasks' metadata (e.g., possible competences to train, level of complexity, and number of aircraft involved) and the regulation prompts. These regulation prompts were repeatedly given on two occasions during the training. One regulation prompt was given *prior* to a task to let students focus on their own learning goals and to orient to and plan how to achieve these goals in the chosen learning task. The other regulation prompt was given *after* a task to help learners assess their performance on this learning task, define their learning needs, and set new learning goals. The development of regulation skills and ATC skills was measured in the integrated condition but also in the original training program, which functioned as the control condition. Results showed better development in the integrated condition than in the control condition for both regulation skills and ATC skills.

No difference in development of SDL skills was found. In line with earlier findings by Kicken et al. (2008, 2009b), the results showed that also in the ATC domain, development of regulation skills and development of domain-specific skills can be fostered simultaneously. The fact that weak results were found for the development of SDL skills seems to confirm the notion that at least a possibility for students to actively take part in the task-selection process is required to train these skills too (e.g., shared control; Chapter 4, Corbalan et al., 2009b, Salden, Paas, & Van Merriënboer, 2006). Nevertheless, the successful development of self-regulated learning and self-efficacy is an important factor towards shared control in adaptive training (Loyens, Magda, & Rikers, 2008). Therefore, the results of the study described in Chapter 5 are promising and an important step towards a fully adaptive training environment.

Chapter 6 presents an overview of the main findings of the studies reported in this dissertation in terms of conclusions, theoretical and instructional implications and limitations. The main conclusions of this dissertation are twofold, pertaining to (1) visual problem-solving strategies, and (2) the integration of self-regulated learning in ATC training.

With regard to visual strategies, the relation is discussed between the level of ATC expertise and three visual strategies unraveled in this thesis (i.e., means-end analysis, information reduction, and chunking). Eye-movement modeling examples (EMMEs) for novices must be designed in such a way that they show which information is needed to work forward to the goal instead of backward from the goal, which information is relevant for problem-solving, and where this information is located in the complex visual representation. EMMEs for intermediates must be designed in such a way that they show which information is minimally required to take safe decisions and so reduce the amount of visual search. EMMEs for experts that must learn to work with new technologies and/or regulations must be designed in such a way that they show which new information elements become important. For experts, EMMEs of peers or even from the experts themselves can also help to foster reflection on the use of own visual strategies. The discussion also stresses the need to integrate cognitive theories with perceptual theories to guide the further development of visual-strategy instruction.

Concerning the integration of developing self-regulation in ATC training, the discussion focuses on the conclusions and implications of a shared-controlled training system. It is concluded that students' can acquire self-regulation skills as an integrated part of their ATC training. Moreover, this directly improves students' development of domain-specific ATC skills as well as their self-efficacy. The results also suggest that students should be given more control over the selection of learning tasks in order to develop their SDL skills. The use of a shared-controlled training system that makes this possible requires a development portfolio that can support the selection of learning tasks based on individual learning goals. Finally, the chapter discusses some limitations of the studies and suggestions for future research.

In sum, it is concluded that an important step forward was made in training complex cognitive skills in a visual domain. The findings show that it is possible to improve the training of air traffic controllers, on the one hand, by extending the training methods for visual problem-solving and, on the other hand, by integrating training methods for self-regulated learning skills in their training program. This will help them to be better prepared for the future.

SAMENVATTING

Luchtverkeersleiders moeten in staat zijn hun functioneren steeds aan te passen aan veranderingen die plaatsvinden in hun technische, complexe en visueel georiënteerde werkomgeving. Die veranderingen hebben vooral te maken met het toenemende luchtverkeer en de daaraan gerelateerde werkprocedures. Er vinden daarom voortdurend aanpassingen plaats in de gebruikte technologie en regelgeving. Dit betekent dat Luchtverkeersleiding (VKL) studenten niet alleen de complexe vaardigheden moeten verwerven die nodig zijn om na hun studie luchtverkeer te leiden. Om zich voor te bereiden op bovengenoemde veranderingen is het ook noodzakelijk dat zij leren hoe zij hun routines kunnen aanpassen zodat zij ook later hun competenties kunnen ontwikkelen om zo te blijven voldoen aan nieuwe eisen. VKL-opleidingen voorzien hier nog niet optimaal in omdat deze opleidingen niet specifiek aandacht besteden aan de ontwikkeling van vaardigheden op het gebied van zelfregulatie en zelfsturing. Daardoor worden studenten niet specifiek voorbereid op leren in de toekomst.

Het hoofddoel van dit proefschrift is tweeledig: enerzijds het uitvoeren van een taakanalyse om in kaart te brengen welke visuele vaardigheden voor VKL van belang zijn, en anderzijds het ontwikkelen van instructie-richtlijnen die eraan bijdragen dat VKL-studenten beter worden voorbereid op een leven lang leren.

Hoofdstuk 1 introduceert het complexe VKL-domein en bespreekt de belangrijkste onderzoeksvragen van dit proefschrift. VKL vereist menselijk handelen met stabiele en hoge kwaliteit om ten eerste zeer veilig maar ten tweede ook efficiënt luchtverkeer te leiden. In veel situaties kunnen dit conflicterende vereisten zijn waardoor het werk van een luchtverkeersleider bestaat uit een voortdurende uitdaging om tot optimale oplossingen te komen. Bovendien is VKL een taak die zich vooral op visuele waarneming baseert en die de correcte identificatie van belangrijke objecten en de interpretatie daarvan vereist. Er is al eerder onderzoek uitgevoerd op gebied van visuele expertise en er is gekeken naar verschillen tussen experts en beginners. Het aantal studies waarbij ook intermediates (gedeeltelijk ontwikkelde vakkundigen) zijn betrokken, is beperkt (cf. Gegenfurtner, Lehtinen, & Säljö, 2011). Om de instructie te verbeteren, is het van belang te bepalen welke visuele strategieën worden gebruikt door de verschillende niveaus van VKL-expertise. De eerste onderzoeksvraag die in dit proefschrift behandeld wordt, gaat hierop in en luidt: *Welke visuele strategieën in VKL worden gebruikt door beginners, intermediates en experts?*

Behalve dat VKL visueel complex is, blijkt het domein zich steeds verder te ontwikkelen. Luchtverkeersleiders worden regelmatig geconfronteerd met ingrijpende veranderingen in de technieken waarmee ze werken en de regelgeving die zij moeten volgen. Daarom moeten VKL-studenten niet alleen de domein-specifieke competenties leren, maar moeten zij ook leren om adequaat te reageren op veranderingen in hun werk, om zo hun expertise gedurende hun werkzame leven te onderhouden. Instructie in VKL moet daarom regulatievaardigheden trainen om luchtverkeersleiders zodanig op te leiden dat zij beter leren bij te blijven met de constant veranderende werkomgeving. De tweede onderzoeksvraag van dit proefschrift is dan ook: *Welke regulatievaardigheden zijn volgens verschillende actoren in de VKL-training belangrijk voor VKL-studenten?*

Aangezien het doel is om studenten regulatievaardigheden aan te leren als geïntegreerd deel van hun opleiding, dient ook de volgende vraag beantwoord te worden: *Wat zijn de eisen aan een leeromgeving die bedoeld is om de ontwikkeling van domeinspecifieke vaardigheden en zelfregulatievaardigheden geïntegreerd aan te leren in een cognitief complex domein als VKL?*

Om de haalbaarheid van geïntegreerd trainen van regulatievaardigheden in de VKL-opleiding te verifiëren luidt de laatste onderzoeksvraag: *Wat is het effect van een geïntegreerde training van zelfregulatievaardigheden op de ontwikkeling van deze regulatievaardigheden bij studenten en op hun domeinspecifieke prestaties?*

Om deze vier onderzoeksvragen te beantwoorden werden vier studies uitgevoerd. Hoofdstuk 2 beschrijft een studie naar de VKL-specifieke complexe competenties en in het bijzonder naar de vaardigheden die gerelateerd zijn aan visuele expertise. Hoofdstukken 3 tot en met 5 concentreren zich op zelfsturende en zelfregulerende leervaardigheden en bestuderen de mogelijkheid deze aan te leren als geïntegreerd onderdeel van de VKL-opleiding om zo de studenten voor te bereiden op levenslang leren. Hoofdstuk 6 geeft een samenvatting van de belangrijkste bevindingen van de vier studies en geeft antwoorden op de onderzoeksvragen die in Hoofdstuk 1 zijn gesteld. Daarbij worden de resultaten bediscussieerd, conclusies getrokken en bespreekt het hoofdstuk de beperkingen van het onderzoek. Tot slot worden suggesties en denkrichtingen voor toekomstig onderzoek gegeven.

De studie beschreven in Hoofdstuk 2 heeft als doel het krijgen van inzicht in de visuele probleemoplosstrategieën van experts, intermediates en beginners. Uit eerder onderzoek blijkt dat mensen met verschillende expertise ook verschillende strategieën gebruiken om complexe visuele problemen op te lossen (Gegenfurtner et al., 2011; Reingold & Sheridan, 2011). Er is nog maar beperkte ervaring met training expliciet gericht op het verkrijgen van de gewenste visuele vaardigheden (Jarodzka, Scheiter, Gerjets, & Van Gog, 2010), terwijl deze vaardigheden wel degelijk van groot belang zijn in veel domeinen (bijv. gezondheidswetenschappen, beveiliging, luchtvaart). Om instructie te ontwerpen die de ontwikkeling van visuele expertise in VKL stimuleert, is het belangrijk te begrijpen welke strategieën experts, intermediates en beginners gebruiken om complexe informatie van een radarscherm te verwerken. Hoe bepalen zij welke objecten relevant zijn om informatie van te verkrijgen (bijv. vliegtuigen met hun snelheden en hoogtes, etc.)? En hoe maken zij beslissingen die gebaseerd zijn op die informatie? Deze studie richtte zich op drie visuele probleemoplosstrategieën: Ten eerste, de object-doel analyse welke bekend staat als een inefficiënte beginnersstrategie waarin de focus ligt op het doel van de vliegtuigen. Ten tweede, de informatiereductiestrategie waarbij de hoeveelheid informatie die voor taakuitvoering verwerkt moet worden geoptimaliseerd wordt door het scheiden van relevante en irrelevante informatie. En ten derde, de groeperingsstrategie die voor efficiënte informatieverwerking zorgt door clusters van relevante informatie als één element te behandelen. De studie had als doel om door middel van eye-tracking te bepalen welke strategie experts, intermediates en beginners in het VKL-domein gebruiken. Daarbij is gekeken naar de versterkende invloed van de moeilijkheidsgraad van taken op het verschil tussen deze groepen. In VKL wordt het aantal mogelijke oplossingen voor luchtverkeerssituaties beperkt door de eisen die aan veilige verkeersafhandeling worden gesteld en door de eis dat deze afhandeling efficiënt gebeurt. Toch zijn er enkele vrijheden in het bereiken van goede oplossingen (bijv. verandering van snelheden, van hoogten of van richting). Voor het optimaal ontwerpen van instructie is het van belang om inzicht te krijgen in het aantal verschillende oplossingen dat acceptabel is wanneer complexe problemen moeten worden opgelost (Medin et al., 2006). De verwachting is dat experts in staat zijn om snel een groot aantal conflictsituaties te herkennen en daarvoor dan snel een goede oplossing weten te vinden. Omdat de meeste van hun oplossingen tot een beperkte set van meest optimale zullen behoren, is het de verwachting dat zij relatief vergelijkbare oplossingen kiezen vergeleken met anderen met minder expertise. Om inzicht te krijgen in de oplossingsverschillen tussen de verschillende niveaus van expertise neemt deze studie ook de vergelijkbaarheid van gekozen oplossingen mee.

Van 31 deelnemers werden oogbewegingen vastgelegd (10 experts, 9 intermediates en 12 beginners) terwijl ze werkten aan negen VKL-taken.. De opdracht voor de deelnemers was om zo snel mogelijk een optimale oplossing voor een statische luchtverkeerssituatie te geven door de volgorde van binnenkomst van vliegtuigen te benoemen. De data-analyse bevestigde duidelijk de hypothese dat experts, intermediates en beginners verschillende visuele strategieën gebruiken om luchtverkeerssituaties op te lossen. Ten eerste gebruikten de groepen met meer expertise de meer effectieve informatiereductiestrategie. Ten tweede gebruikten experts vaker de groeperingsstrategie bij koppelbare objecten dan intermediates en beginners. Ten derde bleken experts gebruik te maken van een strategie om vooruit te werken in plaats van te werken vanuit het doel naar de verschillende objecten (object-doel analyse).

Net als in andere domeinen (bijv., Jarodzka et al., 2010; Medin, Lynch, Coley, & Atran,1997), wordt in deze studie de hypothese bevestigd dat de oplossingen van experts meer op elkaar lijken dan de oplossingen van intermediates. De oplossingen die beginners voorstellen lijken veel minder op elkaar.

Deze inzichten in verschillen tussen experts, intermediates en beginners kunnen bijdragen aan het ontwikkelen van uitgewerkte voorbeelden. De mogelijke oplossingen en de oogbewegingen (UVO's) (d.w.z. gebruik van oogbewegingsregistraties van experts) zijn de basis voor de ontwikkeling van instructie in het gebruik van visuele probleemoplosstrategieën in complexe visuele domeinen.

Hoofdstuk 3 beschrijft een focusgroepstudie met als doel het bepalen van de leerkarakteristieken die vereist zijn om studenten te betrekken in een succesvol VKL-leerproces en om deze karakteristieken volgens belangrijkheid te rangschikken. De studie behandelt daarom drie specifieke onderzoeksvragen: (1) Welke leerkarakteristieken dragen bij aan succesvol leren in VKL volgens de verschillende actoren in de opleiding (d.w.z. trainingsontwerpers, trainers/coaches, en studenten)? (2) Wat zijn de overeenkomsten en verschillen tussen de drie groepen actoren wat betreft de leerkarakteristieken? (3) Wat zijn de overeenkomsten en verschillen tussen de drie groepen actoren wat betreft hun mening over de volgorde van belangrijkheid van specifieke karakteristieken?

Zes onderwijsontwerpers, zeven trainers/coaches en zeven studenten, allen van Luchtverkeersleiding Nederland, deden vrijwillig mee aan deze studie. De deelnemers werden verdeeld in drie homogene focusgroepen: een ontwerpersgroep, een trainer/coachgroep en een studentengroep. De deelnemers maakten een week voorafgaand aan de focusgroepbijeenkomst een voorbereidende opdracht. In deze opdracht werd hun gevraagd aan de hand van een specifiek voorbeeld vanuit een eigen ervaring factoren van succesvol leren op te schrijven. Alle bijeenkomsten werden voorgezeten door dezelfde persoon die de voorbereidende opdracht gebruikte om de bijeenkomsten te structureren. De voorzitter gaf een algemene introductie op het onderwerp en legde de discussieregels uit. Elke bijeenkomst duurde ongeveer twee uur en van alle bijeenkomsten zijn geluidsopnamen gemaakt die werden uitgeschreven tot protocollen. Een kwantitatieve analyse op deze protocollen leverde een ranglijst op van de karakteristieken, gebaseerd op ranglijsten van de drie groepen actoren. Een kwalitatieve analyse maakte vervolgens inzichtelijk waarom bepaalde karakteristieken door de verschillende groepen actoren als belangrijk worden beschouwd voor succesvol leren. De gevonden significante correlatie tussen de drie ranglijsten van de drie groepen actoren duidt op een grote overeenstemming tussen de groepen. Er zijn echter ook verschillen tussen de ranglijsten gevonden. Uit de analyse bleek dat het vermogen om leerdoelen te stellen en het vermogen om hulpbronnen voor leren te identificeren, van groot belang werden geacht voor succesvol leren. Uit de analyse met betrekking tot de verschillen tussen de groepen actoren kan worden geconcludeerd dat studenten niet automatisch denken aan hun leerbehoeften en leerdoelen op het moment dat ze een leertaak uitvoeren. Zij lijken meer te focussen op de uitvoering op zich in plaats van het leren van deze taken. Ten slotte bediscussieert Hoofdstuk 3 wat de implicaties van deze uitkomsten zijn voor het inrichten van instructie zodanig dat voorkomen wordt dat van verschillende actoren de percepties over succesvol trainen uit elkaar lopen. Hiervoor zou een nieuw ontwerp van een VKL-opleiding de ontwikkeling van zelfregulatie (d.w.z. zelfsturende vaardigheden, zelfregulatieve vaardigheden en self-efficacy) moeten stimuleren door het oefenen hiervan te integreren in het trainen van VKL-specifieke competenties. De verwachting is dat hierdoor studenten een grotere verantwoordelijkheid over hun eigen leren krijgen en beter leren in te zien welke leermogelijkheden leertaken bieden.

Er zit een paradox verscholen in leeromgevingen die bedoeld zijn om het trainen van domeinspecifieke vaardigheden en zelfregulatie geïntegreerd te ontwikkelen: een systeem dat studenten de mogelijkheid geeft te leren reguleren op hun eigen leren vereist van deze studenten dat zij al regulatievaardigheden hebben ontwikkeld (Corbalan, Van Merriënboer, & Kicken, 2010). Als oplossing van deze paradox presenteert Hoofdstuk 4 een adaptief trainingssysteem waarin het systeem en de student de controle over leertaakselectie delen. In een dergelijk systeem kunnen studenten worden ondersteund in hun ontwikkeling van zelfregulatie en in het bijzonder hun zelfsturende vaardigheden. Het hoofdstuk bespreekt de eigenschappen van een leeromgeving in een cognitief complex domein zoals VKL waarin de ontwikkeling van domeinspecifieke vaardigheden en zelfregulatie worden geïntegreerd. Er wordt een onderscheid gemaakt tussen adaptieve trainingssystemen (d.w.z. systemen waarin elke student een individueel leerpad volgt) en niet-adaptieve trainingssystemen (d.w.z. systemen waarin elke student een leerpad volgt dat is ontworpen voor de gemiddelde student). Vervolgens worden drie typen van controle over leertaakselectie in adaptieve systemen onderscheiden. Qua type controle wordt eerst een systeemgecontroleerde trainingssysteem besproken. Daarin kiest het systeem (bijv. een coach of een computerprogramma) leertaken. Ten tweede wordt een studentgecontroleerde trainingssysteem besproken waarin de verantwoordelijkheid voor leertaakselectie volledig bij de student ligt. Ten derde wordt een systeem met gedeelde taakselectieverantwoordelijkheid uitgewerkt. Daarin verschuift de verantwoordelijkheid geleidelijk van het systeem naar de student, naarmate de zelfregulatie van de student zich ontwikkelt. Er wordt gepleit dat alleen een systeem met gedeelde controle over taakselectie tegemoet kan komen aan de eisen voor het geïntegreerd ontwikkelen van zelfregulatie in een complex cognitief domein. Een dergelijk systeem garandeert een hoog eindniveau qua domeinspecifieke vaardigheden (d.w.z. een effectieve training), een efficiënte training (een training die continu aansluit op individuele leerbehoeften), een voortdurend bijhouden van de voortgang van de studenten en een geleidelijke en een ondersteunde ontwikkeling van zelfregulatie. De conclusie is dat een dergelijk trainingssysteem met gedeelde controle over taakselectie een oplossing kan bieden voor de paradox. Verder worden de elementen van een adaptief trainingssysteem met gedeelde controle over taakselectie beschreven. Deze elementen zijn: (1) een database met leertaken waaraan metadata zijn gekoppeld en waaruit de taken geselecteerd kunnen worden; (2) een ontwikkelingsportfolio om inzicht te krijgen in de competentieontwikkeling, om leerbehoeften te definiëren en om leerdoelen te stellen, en (3) een coachingsprotocol om het niveau van coachondersteuning aan te passen aan het zelfregulatieniveau van de student.

Hoofdstuk 5 beschrijft een studie over de effecten van een training waarin instructie in zelfregulatie is geïntegreerd in de domeinspecifieke inhoud op zelfregulatievaardigheden, self-efficacy en domeinspecifieke prestaties van studenten in de VKL-praktijk. Voor deze studie is de module ‘Area Control Surveillance’ bij Luchtverkeersleiding Nederland herontworpen. De nieuwe ontworpen geïntegreerde training werd in de studie vergeleken met een controle conditie. In de geïntegreerde conditie werden studenten op gezette momenten verzocht te reguleren ter voorbereiding op leertaakselectie. Dit gebeurde door studenten te laten werken aan werkbladen. De werkbladen bij de leertaken gaven de metadata (bijv. mogelijke competenties die met de taak te trainen zijn, complexiteitsniveau, aantal vliegtuigen in de oefening) en daarnaast gaven ze prompts om te reguleren. Deze prompts werden voor en na het werken aan leertaken gegeven. Voorafgaande aan een leertaak formuleerden studenten zo eigen leerdoelen, oriënteerden zij zich op de leertaak en maakten zij een plan om de gestelde doelen te bereiken. De prompt na de taak werd gegeven om studenten te helpen hun eigen taakprestatie te evalueren, verdere leerbehoeften te definiëren en leerdoelen te formuleren.

De ontwikkeling van regulatievaardigheden en VKL-vaardigheden werd zowel gemeten in de geïntegreerde conditie als in het originele trainingsprogramma (de controleconditie). De resultaten lieten in de geïntegreerde conditie een betere ontwikkeling zien van zelfregulatie vaardigheden en VKL-vaardigheden. Er zijn *geen* verschillen in zelfsturende vaardigheden gevonden. De uitkomsten zijn in lijn met eerdere bevindingen van Kicken en collega’s (2008, 2009b). De resultaten laten zien dat ook in het VKL-domein, de ontwikkeling van zelfregulatie en de ontwikkeling van domeinspecifieke vaardigheden gelijktijdig kunnen plaatsvinden. Het feit dat de ontwikkeling van zelfsturende vaardigheden niet significant toenam, kan de veronderstelling bevestigen dat studenten op zijn minst actief betrokken moeten worden in het leertaakselectieproces om zo die vaardigheden ook te trainen (bijv. gedeelde controle over het leertaakselectieproces; Hoofdstuk 4, Corbalan et al., 2009b, Salden, Paas, & Van Merriënboer, 2006). Echter, de succesvolle ontwikkeling van zelfregulatie vaardigheden en self-efficacy zijn al belangrijke factoren voor een gedeelde controle in een adaptieve training (Loyens, Magda, & Rikers, 2008). Vandaar dat de resultaten van Hoofdstuk 5 een veelbelovende en belangrijke stap zijn in de richting van een volledig adaptieve trainingsomgeving.

Hoofdstuk 6 presenteert een overzicht van de belangrijkste bevindingen van de studies uit dit proefschrift. Op basis van de bevindingen worden conclusies getrokken en de implicaties voor theorie en praktijk worden besproken. De belangrijkste conclusies van dit proefschrift zijn op twee gebieden en hebben betrekking op (1) visuele probleemoplosstrategieën, en op (2) de integratie van zelfregulerend leren in de VKL-opleiding.

Wat betreft de visuele strategieën kan worden geconcludeerd dat Uitgewerkte voorbeelden op basis van oogbewegingen (UVO’s) voor beginners zodanig moeten worden ontwikkeld dat zij laten zien (1) welke informatie uit de visuele omgeving nodig is om oplossingen op te bouwen in plaats van de constructie van een oplossing te laten uitgaan van het doel, (2) welke informatie relevant is voor het oplossen van visuele problemen, en (3) waar deze informatie te vinden is in de complexe afbeelding. UVO's voor intermediates moeten zodanig ontworpen zijn dat zij laten zien welke informatie minimaal nodig is om veilige beslissingen te nemen om zo de hoeveelheid informatie te verminderen die verwerkt moet worden. Voor experts die moeten leren werken met nieuwe technologieën en/of nieuwe regelgeving moeten UVO's zodanig worden ontworpen dat zij inzicht geven in het belang van nieuwe informatie-elementen. De discussie benadrukt verder de behoefte om cognitieve theorieën te integreren met perceptuele theorieën om de ontwikkeling van instructies voor visuele strategieën verder te ontwikkelen.

Wat betreft de geïntegreerde ontwikkeling van zelfregulatie in de VKL-opleiding, focust de discussie op de conclusies en implicaties van een trainingssysteem met gedeelde controle over taakselectie. De conclusie is dat studenten kunnen leren reguleren als geïntegreerd onderdeel van hun VKL-opleiding. Bovendien stimuleert een geïntegreerde aanpak de ontwikkeling van VKL-specifieke vaardigheden en self-efficacy. De resultaten pleiten ervoor dat studenten meer controle over de selectie van hun leertaken zouden moeten krijgen om ook hun zelfsturende vaardigheden te trainen. Het inzetten van een trainingssysteem met gedeelde verantwoordelijkheid voor het taakselectieproces vereist een ontwikkelingsportfolio dat ondersteuning kan bieden bij het selecteren van leertaken die aansluiten bij individuele leerdoelen. Ten slotte bediscussieert het hoofdstuk enkele beperkingen van de studie en worden er suggesties gedaan voor toekomstig onderzoek.

Samenvattend kan worden geconcludeerd dat een belangrijke stap is gezet in de ontwikkeling van kennis over het trainen van complexe cognitieve vaardigheden in een visueel georiënteerd domein. De bevindingen laten zien dat het mogelijk is om de opleiding tot luchtverkeersleider verder te verbeteren door aan de ene kant de trainingsmethoden voor visuele probleemoplosstrategieën uit te breiden en door aan de andere kant een integratie te bewerkstelligen van de ontwikkeling van zelfregulatie en domeinspecifieke vaardigheden. Dit zal helpen om de luchtverkeersleiders nog beter voor te bereiden op hun toekomstige werkzaamheden.

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