Didactics in simulator-based driver training: current state of affairs and future potential

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Abstract

Moderate-fidelity driving simulators are increasingly being used for cost-effective initial driver training. Apart from the need to satisfy simulator fidelity requirements, more attention is needed on the didactical properties of the training programs in order to yield more effective training. This paper investigates the didactical properties of current driver training simulators, and provides recommendations for improving the instructional design. A survey shows that the intelligent tutoring systems of current driver training simulators are mostly imitating the human instructor and that the “first principles of instruction” (Merrill, 2002) are not implemented to their full potential. Hence, there is ample room for improvement of the didactical properties by fully exploiting the many visualization, demonstration and performance-assessment opportunities provided by modern driving simulators. Furthermore, objective performance ratings of students can be used to provide accurate and consistent feedback-on-performance, something that is not possible in real cars, but which is often essential for effective skills training. It is recommended to use empirical experimentations to improve the instructional design of simulator-based driver training for specific learning outcomes and validate the use of the first principles of instruction to facilitate learning.

Résumé
Introduction

An increasing number of driving schools are integrating simulators in their driver training curricula. Although simulators are already used extensively for driver training, their potential for training may be increased if more emphasis in the development of driver training simulators is placed on the didactical aspects of the training program, such as the instructional design or the measures with which driver performance is rated. Driving simulators are developed for various purposes, such as research, entertainment or training. As far as training is considered, simulators provide many advantages as compared to driving on the road. Examples are the measurement of driving performance (Hoeschen et al., 2001; De Winter et al., 2006), the possibility to train in purposefully developed learning environments (Hoeschen et al., 2001) and the increased opportunities to present information and provide feedback using various modalities (De Groot et al., 2006). Automated training offers further economical advantages, if the human driving instructor is replaced by an automated tutoring system. However, where a human teacher may adapt and compensate for flaws in the learning materials, the learning materials have to be of excellent quality if they are to stand on their own (Barnard, 2006). Several researchers have indicated that the didactical aspect of simulator based training programs should receive more attention (e.g. Salas, 1998, Kappé and Emmerik, 2005). Example questions that need to be addressed regarding the didactical aspects are: “What are the didactical properties of simulator-based driver training at this moment?”, and “How can the didactical properties of simulator-based driver training be improved?” To answer these questions, a way to describe the didactical properties is necessary.

Didactics in driver training

The effectiveness of a training program can be determined quantitatively (how much is learned given a certain amount of training time) or qualitatively by investigating for example the instructional design of the program. A quantitative analysis was performed with data from one specific driving school which used an additional human instructor to assist the automated training on their simulators (de Winter et al., 2007). Data from this school was compared with data from other driving schools using the same simulator without the extra human help (as it is intended). Results are presented in Table 1. The scores have been normalized such that for the total group (n=859), the mean is equal to zero and the standard deviation is equal to one.

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Human help (n=39)</th>
<th>No human help (n=820)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Error-score (based on number of erroneous tasks)</td>
<td>0.05</td>
<td>0.49</td>
</tr>
<tr>
<td>Error percentage-score (based on number of errors with respect to the total number of attempts)</td>
<td>0.31</td>
<td>0.57</td>
</tr>
<tr>
<td>Correct-score (based on number of correct tasks)</td>
<td>-1.39</td>
<td>0.72</td>
</tr>
<tr>
<td>Speed-score (based on average task time)</td>
<td>-1.7</td>
<td>0.83</td>
</tr>
<tr>
<td>Pass rate on first practical exam [%]</td>
<td>49</td>
<td>51</td>
</tr>
<tr>
<td>Days from first sim. lesson to driver license [days]</td>
<td>235</td>
<td>86</td>
</tr>
</tbody>
</table>

1) Measures and “no human help” data obtained from De Winter et al., 2007 (internal report)
Results show that more tasks lead to errors, fewer tasks are executed correctly, and, on average, tasks take more time to complete when human instructions are added to the automated instructions. This example shows that students training on systems using an intelligent tutoring system do not necessarily benefit from extra human attention. Instead of helping as he intended, the human instructor unwillingly delayed the training with his extra instructions and feedback and introduced extra information to process for the students, thereby reducing the learning performance during the lesson. This example shows that that automated training can outperform training by a human instructor and that simulators have potential to standardize and objectify training programs. Additionally automated training programs can benefit from using proven educational techniques which are used methodologically to develop them.

**Goal of this article**

This article will qualitatively analyze the quality of instructional designs of driver training simulators and provide suggestions for improvement. The evaluation includes the instructional designs of four selected moderate-fidelity driver training simulators which are available for Dutch driving schools: 1) The ANWB simulator (including the supporting computer-based training lessons) [www.anwb.nl](http://www.anwb.nl) developed by ST-software [www.stsoftware.nl](http://www.stsoftware.nl), 2) The DriveZone simulator (DZ) [www.drivezone.nl](http://www.drivezone.nl) developed by VSTEP [www.vstep.nl](http://www.vstep.nl), 3) The Dutch Driving simulator (DDS) developed by Green Dino [www.greendino.nl](http://www.greendino.nl), and 4) The VR-systems simulator (VR) [www.vrsystems.nl](http://www.vrsystems.nl) developed by dr. Foerst [www.drfoerst.de](http://www.drfoerst.de). The article is intended to give a general impression of the current state of affairs concerning the didactics of commercially available driver training simulators, not to compare or classify the evaluated simulators.

**Method**

The instructional design of the simulator-based driver training programs will be analyzed using the ‘first principles of instruction’ (Merrill, 2002a). Merrill derived the first principles from the major instructional design theories and models and are applicable for both knowledge as well as (motor-) skill acquisition. The first principles are presented here as questions, just like in Merrill (2002b), because this allows for an easier analysis. If there is an affirmative answer to the questions, learning is incrementally improved. The first principles of instruction (Merrill, 2002b):

1. **Problem-centered**: Is the courseware presented in the context of real-world problems? Are learners shown the problem, engaged at the task as well as the operation level, and involved in a progression of problems?
2. **Activation**: Does the courseware attempt to activate relevant prior knowledge or experience? Are learners directed to recall relevant past experience or provided relevant experience? Are they encouraged to use some organizing structure?
3. **Demonstration**: Does the courseware demonstrate what is to be learned rather than merely telling information about what is to be learned? Are the demonstrations consistent with the instructional goals? Is learner guidance employed? Do media enhance learning?
4. **Application**: Do learners have an opportunity to apply their newly acquired knowledge or skill? Is the application consistent with the instructional goals, and does
it involve a varied sequence of problems with feedback? Are learners provided with gradually diminished coaching?

5. **Integration:** Does the courseware provide techniques that encourage learners to integrate (transfer) the new knowledge or skill into their everyday life? Do learners have an opportunity to publicly demonstrate their new knowledge, reflect on their new knowledge, and create new ways to use their new knowledge?

The existence of the first principles of instruction in an instructional design can be used as a framework to analyze the didactical properties of the design. The discussion in the next section aims to answer the following two questions, along the lines of the first principles of instruction:

1. What are the didactical properties of current instructional designs?
2. What are the possibilities to improve the instructional designs?

**Results**

**Principle number one, problem-centered**

Learning is promoted when learners are engaged in solving real-world problems. Merrill uses the word ‘problem’ to indicate a wide range of activities, with the most critical characteristics being that the activity addresses the whole task rather than only components of this task, and that the task is representative for those tasks which the learner will encounter in real life.

- Is the courseware presented in the context of real-world problems?
  
  **Currently:** Most simulators start their lessons with a spoken and/or written message containing the general learning goal of the exercise, sometimes making use of pictures of real world situations (ANWB), followed by procedural comments on the required actions of the students during the lesson, not with a clear presentation of a real-world problem (ANWB, DZ, DDS).
  
  **Possibility:** Students should be shown the whole task as it is performed in the real world to solve a relevant problem. A movie should be shown, including verbal and/or visual supporting information.

- Are learners shown the problem, engaged at the task as well as the operation level, and involved in a progression of problems?
  
  **Currently:** Simulator-based driver training programs focus on the operation level, and do not explain why certain procedures are valuable, or what happens if the procedures are not followed correctly. For example during the drive-away lesson on the DDS, the instructions explain when the clutch should be operated, and how fast, without informing the student why it needs to be done like that or what happens else.
  
  **Possibility:** The students should be involved at the problem level, not just at the operation, procedure or action level. This can be done by explaining the whole problem and associated difficulties. For the drive-away task described above (at the current situation), the function of the clutch must be explained, including possible results of too fast or too slow clutch pedal release.
Principle number two, activation

Learning is facilitated when existing knowledge is activated as a foundation for new knowledge or skills.

- Does the courseware attempt to activate relevant prior knowledge or experience?
  
  Currently: The introduction of the lesson is used to explain students the goal of the lesson, but it generally fails to check whether the required skills are present or to activate skills required for the exercise (ANWB, DDS, VR).
  
  Possibility: An exercise could be performed prior to the actual lesson to test some of the required skills to perform the lesson. Results of this test could be used to adjust the starting level difficulty of the lesson to the individual skills of the student, and activates the skills and knowledge necessary for the lesson.

- Are learners directed to recall relevant past experience or provided relevant experience?
  
  Currently/possibility: When there is no possibility to use relevant past experience as a base for new knowledge or skills, relevant experience must be provided. The gear-change lesson on the DriveZone simulator (DZ) is a good example of this kind of activation. Students performing this exercise are real beginners, without knowledge of the car controls. The gear-change lesson starts with part-task training to familiarize them with the operation of the gear lever, using a simple screen showing the H-pattern of the shifting lever. Before gear changes are practiced including lateral control of the vehicle, familiarization with the relevant individual controls is established.

Principle number three, demonstration

Learning is promoted when the instruction demonstrates what is to be learned, rather than merely ‘telling’ the student what is to be learned.

- Does the courseware demonstrate what is to be learned rather than merely telling information about what is to be learned?
  
  Currently: Demonstrations are used in many instructions, but there is no structural integration in all of the exercises. Also, demonstrations are often slow-motion action sequences, focusing on the task procedure. Although the procedure or action sequence itself becomes clear during the demonstration, it neither gives the student a clear idea of what a successful task completion looks like, nor what the consequence of bad execution is (DDS).
  
  Possibility: Demonstrations can be used in all lessons to give the students a clear idea of what is required from them. Next to the slow-motion demonstrations to explain the correct procedures, also real-time demonstrations showing reference or goal behavior could be useful.

- Are the demonstrations consistent with the instructional goals?
  
  Demonstrations must be consistent with the intended learning outcome. Gagné (2005) defined five learning outcomes: 1) intellectual skill, 2) cognitive strategy, 3) verbal information, 4) attitude, 5) motor skill; each requiring different learning conditions for effective learning. Both Gagné (2005) and Merrill (1997) identified how to adapt training to specific learning outcomes.
  
  Currently/possibility: Procedure training, as defined by Merrill (1997), requires a demonstration which presents the student with the task to be accomplished, with a list
of the steps and their order. Each step must be demonstrated in detail. If the procedure is applicable in various situations, demonstrations of additional cases are required. The drive-away task is a good case where procedure training is relevant. The Dutch Driving simulator demonstration during the drive-away lesson contains most elements needed for the procedure learning outcome, focusing on the order of execution and highlighting the important aspects to the students.

- **Is learner guidance employed?**
  
  **Currently/possibility:** During the demonstration the learner needs guidance to direct attention towards structural features of the task. During the demonstrations that are presented on simulators, attention is generally focused by zooming in, using slow-motion videos of action sequences or showing detailed pictures (ANWB, DZ, DDS).

- **Do media enhance learning?**
  
  **Currently/Possibility:** The modalities in which information and feedback are presented should be tuned for optimal information transfer. During most instructions visual images or movies are combined with a spoken voice. Sometimes this is extended with redundant visual text messages. Presenting the information both visually and verbally is preferred, as different people have different optimal information input channels.

**Principle number four, application**

Learning is promoted when learners are required to use their new knowledge or skill to solve problems (practice).

- **Do learners have an opportunity to apply their newly acquired knowledge or skill?**
  
  **Currently:** Simulators are mainly used to practice the complete driving task, just like it is practiced in the real world (ANWB, DZ, DDS, VR).
  
  **Possibility:** More focus on the application of new knowledge or skills is possible during the application phase. The elements of focus in a specific lesson deserve extra attention concerning the feedback and general exercise design.

- **Is the application consistent with the instructional goals, and does it involve a varied sequence of problems with feedback?**
  
  **Currently:** Varying types of environments are used for different instructional goals. Variation during the lesson is often implemented through the behavior of other vehicles which show up at different locations randomly. Feedback is generally limited to extrinsic feedback in the form of auditory verbal feedback from a (virtual) instructor (ANWB, DZ, DDS), or text messages appearing in the screen (VR).
  
  **Possibility:** The practice must be consistent with the intended learning outcome. Concerning procedure training, Merrill (1997) states both intrinsic feedback, observing the consequences of a given action or set of actions, and extrinsic feedback, informing the student about the appropriateness of a given action or set of actions, should be available. Especially augmentation of the intrinsic feedback (for example highlighting lines or displaying performance scores after tasks) is a potential advantage of simulator-based training compared to driver training on the road which is hardly used at this moment.

- **Are learners provided with gradually diminished coaching?**
  
  **Currently/possibility:** For the extrinsic feedback which is given by intelligent tutoring systems or human instructors the gradual decrease is implemented well, for example feedback is decreased after a certain number of successful task completions (DDS).
Principle number five, integration

Learning is promoted when learners are encouraged to integrate (transfer) new knowledge or skill into their everyday life.

- **Do learners have an opportunity to publicly demonstrate their new knowledge, reflect on their new knowledge, and create new ways to use their new knowledge?**

  **Currently/possibility:** The simulator-based training should be made a part of a student’s everyday life. A good example of how this can be done is making the driver training results publicly accessible. This is done by the Drivemasters portal (www.drivemasters.nl), where obtained training results are publicly visible and a competition element is added based on training results. Some training programs (ANWB, VR) focus more on the reflections of students after the lessons, using replays or discussion sessions.

![Figure 1: Screenshot of the Drivemasters website (www.drivemasters.nl)](image-url)

Discussion

Summary of results and implications

An instructional design evaluation using Merrill’s ‘first principles of instruction’ revealed that all principles can be implemented on simulators and that there are many possibilities to improve the existing driver training programs. Although the instructional designs of the simulators that were investigated all contain elements of the first principles of instruction, none of the simulators includes all of the elements. The simulators could all benefit from a didactical framework which is structurally used during the development of their individual lessons. Especially in the application phase, simulators are not only used to simulate the car and the environment, but to simulate the complete real world driver training, including the feedback and instructions. Simulators still have a lot of potential for improvement of training effectiveness by using intrinsic and extrinsic feedback mechanisms specifically designed for a certain training task. Because much more information concerning the state of the vehicle and the environment is available in a simulated environment compared to a real world environment, objective and valid
performance measures could be used to present the student with feedback-on-performance which is not possible during real world driver training.

Reflections on the first principles of instruction
Merrill (2002a) extracted the first principles of instruction from some of the major instructional design models (e.g., Star Legacy, 4-MAT, Collaborative problem solving, Constructivist learning environments, 4C/ID Model, Learning by doing), of which many are included in the book of Reigeluth (1999) concerning instructional design theory. Merrill states: “As an instructional program implements more of the first principles of instruction, then there will be a corresponding increase in the quality and amount of learning that will occur.” This hypothesis is not empirically tested. Merrill assumes that if a principle is included in several instructional design theories, the principle has been found either through experience or empirical research to be valid.

The first principles of instruction show some resemblance to the well-known and widely adopted “nine events of instruction” as defined by Gagné (1985; 2005). These elaborate more on the presentation of feedback during application of newly acquired knowledge or skills. Concerning feedback, Merrill states in the diminishing-coaching corollary of principle number four that learning is promoted when learner are guided by appropriate feedback and coaching, including error detection and correction, and that learning is promoted when coaching is gradually withdrawn. In literature about driver training it is also noted that feedback-on-performance is essential for the learning of complex skills as driving (Groeger, 2004). Skills are learned better and faster, if learners are given clear and immediate information of the effects of their actions on the measures which are used to analyze their performance (Romiszovski, 1999).

Both Gagné (2005) and Merrill (1997) stress the importance of an adaptation of the instructional design based on the objective learning outcome. The adaptations needed for the learning outcomes associated with car driving (i.e., procedure strategy, motor skills) are possible on simulators and are more difficult in real-world driving lessons. This is an advantage of simulator-based training that must be exploited further in order to strengthen the position of simulators in the driver training curriculum.

Conclusions and recommendations
The first principles of instruction provide a means to analyze the didactical quality of simulator-based driver training. Following the evaluation two conclusions can be drawn:

- It is possible to implement all five first principles of instruction in simulator-based driver training programs.
- None of the analyzed simulator-based training programs integrates all five principles in its program.

It is hypothesized that the didactical quality of training can be further increased if the principles of instruction are implemented in a more systematic fashion in driver training simulators. It is recommended to use empirical experimentations to improve the instructional design of simulator-based driver training for specific learning outcomes and validate the use of the first principles of instruction to facilitate learning.
Acknowledgements

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