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Redefining Question for Curve-Driving Practice Using Augmented Reality and Driving Models

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Abstract: The purpose of this paper is to suggest a learning support system for curve driving that uses augmented reality (AR) and a model of curve driving. This learning environment focuses on the processes of recognition, judgment, and operation with an aim to enhance driving skills and tackle problems faced while learning how to drive. Driving entails an above cycle that is usually learnt through trial and error while it is practiced initially. Currently in Japan, the driving teacher provides instruction based on the accuracy of the learner's operation, indicating that this learning method is focused on an 'operation.' When the teacher indicates an error in the learner's operation, the learner has to consider the cause of the error by reviewing recognition, judgments, and operation from the teacher's instructions. However, this method of consideration must be inferred and difficult for a novice driver. Moreover, the act of learning recognition, judgment, and operation separately is impossible because humans cannot divide them during driving. In this study, we developed a learning support system that can grasp recognition, judgment, and operation gradually and individually, based on driving models, AR for curve driving, scaffolding and fading, and reflective method. We designed a model of curve driving based on a situation awareness model. The learning environment implemented in this driving model can grasp recognition, judgment, and operation in fixed steps by information displayed in AR and can correct its own recognition, judgment, or operation by reviewing the result of each practice. This exercise will address the constraints and problems faced in tasks that involve learning curve driving; the question of the driving practice can be changed from "How do you drive a curve properly?" to "How do you perform recognition, judgment, and operation when you drive a curve properly?" We also conducted an experiment using the proposed learning support to test its effectiveness.

Keywords: skill learning, driving education, augmented reality, scaffolding, reflective method

1. Introduction

Safety is of utmost importance when one is learning how to drive automobiles. In Japan, when learning how to drive, the learner is instructed to observe the teacher's driving method—that is, pay attention to the method of driving and learn what to look out for. When learning how to drive around a curve, the learner is shown via demonstration, where to slow before the curve and to observe the shape of the curve. The driving instruction and the problem (assignment) can vary according to the instructor and often, the only goal stressed on, when practicing driving, is to drive safely. This emerges as problematic and we disagree with this method of assignment for both learners and teachers.

The ability to drive an automobile requires learning a skill based on practical experience. Therefore, it is natural that instruction be given based on results of the driving operation when learners practically experience the act of driving automobiles. This type of learning often called skill learning. While driving requires comprehension of how to operate a tool (in this case, a car), it also involves learning a cycle of recognition, judgment, and operation (Endsley, M. R, 1995). However, the driver is given the question "How do you drive a curve properly?" This is a very vague question. What learners need to learn is a cycle of recognition, judgment, and operation. Moreover, learning this cycle is very difficult because learners continuously and simultaneously perform recognition, judgment, and operation while they practice driving. To this effect, when teachers provide learners with feedback on the results of judgment, learners cannot necessarily stop driving when done with the judgment, nor can teachers know results of the learner's judgment as it will be practiced at a later time. For this reason, learner is given a vague question, the assignment of driving practice should be to execute driving operations successfully and evaluate results generally.

We developed a learning environment in which recognition, judgment, and operation can be separately and gradually learned, utilizing a heads-up display (HUD) incorporating AR systems. We designed a model of curve driving based on the situation awareness (SA) model. We then considered a practice based on this model and developed a learning environment using HUD that can grasp recognition, judgment, and operation separately and methodically. This was done in an attempt to refine the problem definition and evaluation of driving training from “operation-based” to “recognition, judgment, and operation based.”

Research has largely been based on automatic driving technology in order to realize safe driving (Wei, J. et al., 2013). For instance, there is research on improving accuracy of sensors used in automatic driving (Bojarski, M. et al., 2016). Fully self-driving cars do not require a driver, but low-level self-driving cars require a driver to partially drive. Moreover, full automation can cause cognitive decline of driver and more serious accidents (Parasuraman, R., & Riley, V., 1997). Cars are driven not only for transportation purposes but also for recreation. Therefore, it is important to improve the quality of driving instruction and learning in order to maintain human enjoyment (of driving as a hobby) and ensure road safety.

The following section describes a model of curve driving and learning method based on this model. Section 3 introduces a learning environment for realizing the learning method introduced in section 2. Section 4 compares this study with related studies and section 5 reports results of the practical use of our proposed learning environment. The paper concludes with a summary and suggestions for future applications.

2. Curve Driving Model and Learning Proposal

In order to develop a learning environment that can separately and gradually help learn curve driving through recognition, judgment, and manipulation, we designed a model of curve driving. Based on this model, we show how to realize the learning of recognition, judgment, and operation.

2.1 Curve Driving Model

Driving a car involves dynamic interplay of recognition, judgment, and operation. In the field of Human Factor, the SA model is proposed, which explains the cycle of recognition, judgment, and operation in greater detail (Endsley, M. R., 1995). In this model, the learner at first recognizes elements of external information, then integrates the recognized information and understands the situation, and finally, predicts an operation for approaching a target situation and determines an appropriate operation. Following these four steps, the performance of the decided action is verified, and external information that changed because of the performed action is recognized. Learners will be able to understand this cycle and perform it automatically in driving practice. Motorcycle driving research indicates that the monitoring skill for own driving is important for better driving (Watson, B. C., Tunnicliff, D. J., White, K. M., Schonfeld, C. C., & Wishart, D. E., 2007). In this study, we develop a learning support system for driving practice in curve driving so that learners acquire the driving cycle appropriately.

Figure 1 depicts an instructional textbook from a driving school in Japan on practicing curve driving. The learner is presented with positions and operations necessary for curve driving. The learner repeats driving practice based on this method, and the teacher instructs whether the learner’s driving is appropriate or not, while the learner is driving. On the other hand, driving is inherently, a cycle of recognition, judgment and operation. So, the learner has to learn not only operation but also recognition and judgment. Therefore, above learning is not appropriate because the learner is not even asked a question about the driving process. The driving process that the learner has to learn is not given the learner as question clearly.

Therefore, we constructed a model of a curve driving based on SA, as shown in Figure 2. The model of curve driving is described separately in terms of recognition, judgment, and operation, while the elements of each process remain connected. The driver first recognizes the position of the vehicle, the shape of the curve, the vehicle speed, and the distance to the curve in order to determine the appropriate operation at the curve. Then, the driver predicts the appropriate traveling line and the appropriate traveling speed according to the shape of the curve. Based on the appropriate traveling line and the position of the vehicle, the necessity of steering wheel operation is judged. If the steering wheel operation is required, the degree of steering is also specifically judged. Moreover, by knowing the correct speed required at the curve, the current vehicle speed, and the distance to the curve, it is possible to judge the need for acceleration and deceleration. If acceleration or deceleration is necessary, it is gauged how much acceleration or deceleration needs to be performed. Finally, based on the predicted degree of acceleration and deceleration and the degree to which the steering wheel is turned, these operations will actually be performed and verified. Although these procedures are basically fine-tuned continuously when the driver is driving, we define this granularity model to keep it at a level that humans can understand.

In addition, in Japan, as shown in Figure 1, the above-mentioned cycle is divided into three sections: at the entrance, along the curve, and at the exit. For example, if traveling ahead of the entrance of the curve, the shape of the curve to be grasped becomes the shape of the entrance. When traveling at the entrance of curve, the driver has to be aware of the shape of the curve.

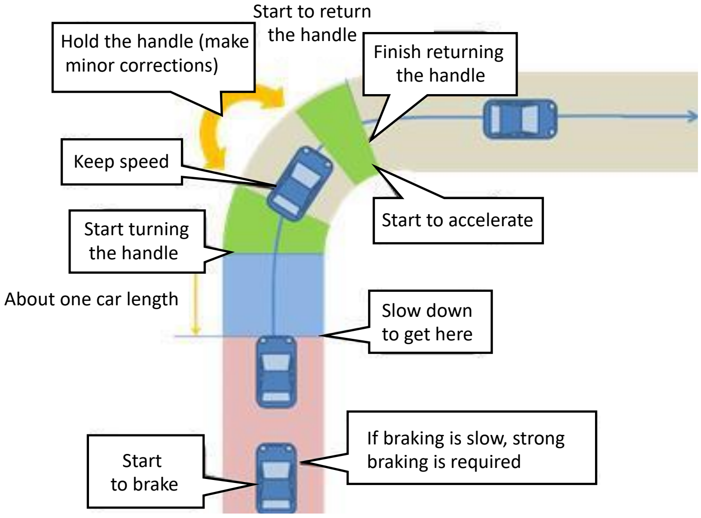


Figure 1. Instructions of curve driving from a Japanese driving textbook.

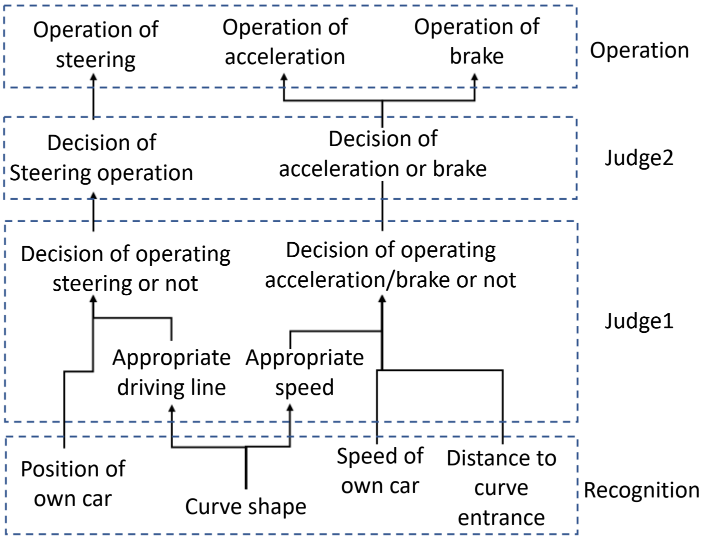


Figure 2. Model for curve driving.

2.2 Redefining Question in Curve-Driving Practice and Its Learning Procedure

2.2.1 Design Policy

Curve driving is classified as motor skill learning because it involves movement of the body. Motor skill learning is generally considered a neuronal change that enables organisms accomplish motor tasks faster and more accurately than before (Diedrichsen, J., & Kornysheva, K., 2015). Skill learning, unlike declarative knowledge, cannot be measured in terms that we can verbalize, and instead, the results of learner activity are evaluated. Skill learning is distinguished from normal exercise adaptation. As mentioned above, it is important to review the results of one's own driving when learning how to drive a motorcycle. We believe the same to be true for when learning how to drive a car. Therefore, the core determinants for learning driving skills are: (a) refining the process of motor tasks by understanding the cycle of recognition, judgment, and operation appropriately; (b) the ability to practice the process of motor tasks repeatedly through trial and error; and (c) refining motor skills by reviewing the processes of motor tasks. Learning environment has to give an assignment so that the learner can learn above.

However, at least in Japan, the learning method for driving a car only requires repeated practice of driving, and teaching how to drive based on this model is insufficient. We believe this is why it is virtually impossible for teachers to indicate and correct learner's errors at every step of recognition, judgment, and operation. However, an appropriate exercise for skill learning is to grasp recognition, judgment, and operation and their connections individually, and to understand these processes and repeatedly refine the process of motor skill. Therefore, based on the driving model in the previous section, we propose a learning method that can comprehend recognition, judgment 1, judgment 2, and operation individually and refine the cycle of these steps.

2.2.2 Learning Procedure

In the previous section, we defined the activity of recognition, judgment 1, judgment 2 and operation for curve driving. We also demonstrated that all of these steps can be presented as visual information. Therefore, if this model is implemented in learning environment, it is possible to present this information appropriately using AR. In the proposed method of learning, learners learn each step of the cycle gradually by being presented with information of the next step in advance. Figure 3 shows an instructional diagram of this learning method. At first, the learner practices the operation. At this time, the result of judgment 2 is displayed to the learner. Therefore, the learner does not need to consider recognition, judgment 1, and judgment 2, and can focus only on practicing the operation. In other words, learners are given the question: "What is the proper operation to safely drive this curve?" This method of reducing the learning load on the learner by adding appropriate support during learning is called scaffolding (Wood, D, Bruner, J. S., & Ross, G., 1976; Jackson, S. L., 1996). After driving practice, the learner reviews the driving operation for its effectiveness, and thus improves their operating skills. The information displayed for scaffolding is different along the curve—at the entrance, in the curve, and at the exit. In this procedure, the learner practices curve driving, reviews the learner's practice, and repeats these processes until the skill has been acquired by the learner.

After mastering operation, the learner is then presented with the results of judgment 1, which are acceleration or deceleration or neither, steering wheel operation or not, appropriate travel line, and appropriate travel speed. Therefore, the learner is given the new question: "How is the appropriate degree of acceleration / deceleration and steering operation to safely drive this curve?" This removal of scaffolding in learning is called fading (Jackson, S. L., 1996). In this case as well, the learner reviews own driving operation, and this time, verifies whether or not judgment 2 skill is appropriate. If the learner's operation is insufficient, the learner can return to previous practice.

When the second step of this learning method is completed, the learner is presented with two tasks of recognition relating to curve shape and speed of the car being driven. The learner is required to perform appropriate judgment 1. As for appropriate driving line in Judgment 1, it is appropriate to drive keeping along the left edge of the curve in Japan, so it is necessary to inform the learner about this stipulation in advance. It is also necessary to inform the learner about the basic driving method shown in Figure 1. After driving practice, the learner reviews operations as before for acquiring judgment 1 and practices driving again to refine the skill. At this stage, based on the driving process, the learner acquires the ability to accurately predict parameters for proper curve driving and ground them to real operation.

After the above practice, the learner eventually removes all the scaffolding and practices driving the car as a regular driving student while being aware of the cycle learned above. By repeating this practice, learners can improve driving operations based on the processes acquired up to the previous step. As for the problem of driving activities in motorcycle driving, it was highlighted that drivers accustomed to driving will drive dangerously based on their own driving experience (Biral, F., Bosetti, P., & Lot, R., 2014). This is because they are familiar with driving operations and are believe that this driving operation is safe as they have never before met with accidents using these driving methods. Considering these factors, this learning method let the learner clarify the elements which should be understand in learning. Thus, this learning method is suggest to be useful in improving the predictive ability during driving and understanding an appropriate cycle for driving.

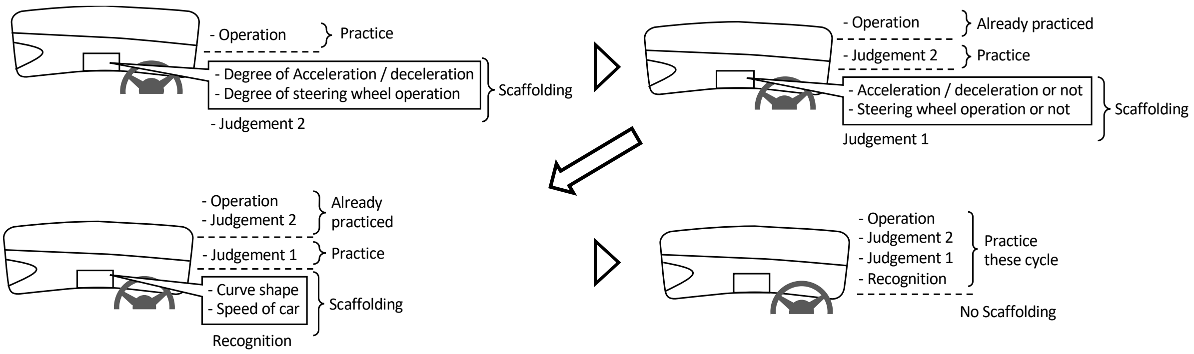


Figure 3. Procedure of suggested learning method.

2.2.3 Reflection on Learning

The feedback generation pattern in each step of the learning process is depicted in Table 1. The operation column indicates the type of driving operation expected of the learner. The position column depicts the position of the car, that is, at the curve's entrance, middle, or exit. Based on these operations and positions, the learner provides reasons for the his/her driving operation during practice. For example, regarding the steering wheel operation at the entrance of the curve, options include: the car position was inside, outside, and no choice. If the learner answers "no choice," it indicates that the driving was appropriate, so no particular feedback is generated. Therefore, it is not described in the

Table 1

A pattern of feedback for learning

Operation	Position	Results of driving	Feedback for recognition	Feedback for judgment	Feedback for operation
Steering wheel	Entrance	Driving position is inside	Recognize the shape of the curve	Judge the proper timing for operation	Operation is early
		Driving position is outside			Operation is late
	Middle	Driving position is inside			Operation is much
		Driving position is outside			Operation is least
	Exit	Driving position is inside		Judge the proper timing for operation	Operation is late
		Driving position is outside			Operation is early
Acceleration / Deceleration	Entrance	Feeling internal force	Recognize the proper speed	Judge the proper timing for operation	Deceleration is late
	Middle	Feeling internal force		Judge the proper degree of operation	Deceleration is not enough
	Exit	Feeling internal force	Recognize the legal speed	Judge the proper timing for operation	Acceleration is late

table. When the learner practices driving and does not use any scaffolding, feedback such as "recognize the shape of the curve" are provided. If the learner is learning judgment and requires driving instructions for the curve's entrance, feedback like "pay attention to the timing of moving the handle" are given. For instance, if the learner answers about driving in the middle of a curve, feedback like "rethink the degree of operation" is given. Finally, if the learner is practicing the operation, the feedback for driving at the entrance of the curve will relate to the operation being early or late. These feedback patterns were created from the model in section 2.1.

3. Design and Development of Learning Support Environment

The interfaces of our learning environment are depicted in Figures 4, 5, and 6. The system was developed using Android Java, and the interface shown in Figure 4 depicts a tablet view. A translucent screen is cast to the HUD (indicated by a white arrow) and positioned directly in front of the driver, as seen in Figure 5. After logging into the system, the learner can select from two options: learn prior knowledge for driving or practice driving step by step. With the first option, the learner is presented with a detailed explanation of Figure 1. When the second option is selected, the learner is required to select which step of the learning described in section 2.2 is to be practiced. The choices are categorized by recognition, judgment 1, judgment 2, and operation.

As this system is intended to be used by teachers at driving schools, information presented in Figure 4 is displayed when the instructor touches the screen on a tablet. The system stores information regarding all the curves of the course that are to be practiced. This software is currently operated using the Gran Turismo 6 simulator and cannot automatically present information for scaffolding based on the actual travel position as the software is not connected to Gran Turismo 6. Therefore, the instructor must change the information displayed for scaffolding appropriately by operating the tablet. Since the information displayed is different for the entrance, middle, and exit of the curve, the instructor must touch the tablet's screen and change information each time the learner moves. However, the information displayed is automatically determined based on the selected step of practice, and the instructor only has to change information for speed using three options: decelerate, maintain, and accelerate. For road use, GPS and Google Maps can be used to automatically obtain speed and curve shape, however, the experiment is yet to be realized from the bioethics viewpoint.

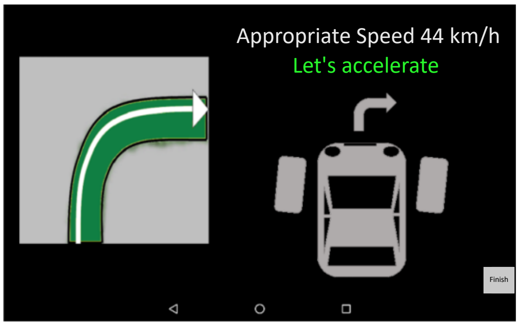
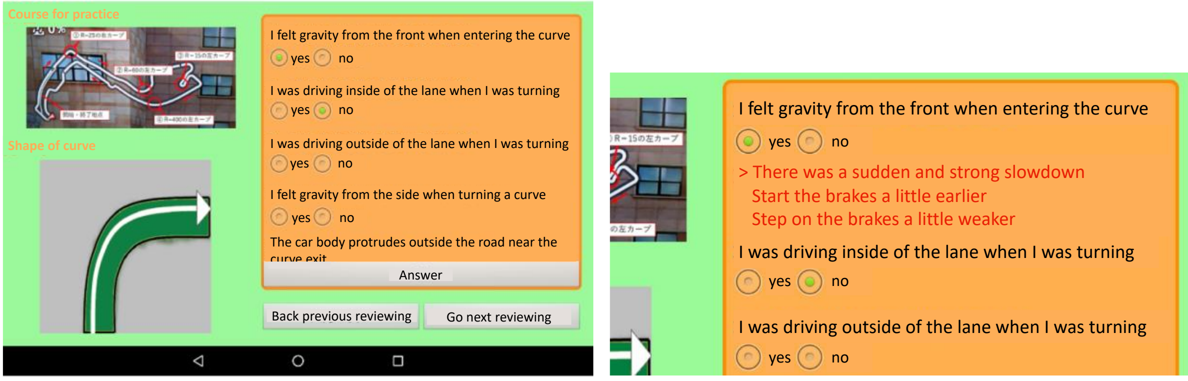


Figure 4. Interface of driving training on an Android tablet.

Figure 5. Interface of driving training on HUD (indicated by white arrow).



(a) Interface before answer (b) Interface after answer

Figure 6. Interface for reviewing as reflective method.

Upon completing practice of all curves of the registered course, the screen switches to a review screen for reflection, as seen in Figure 6. In this interface, the learner reviews the quality of driving performed while checking each curve of the course. Feedback is generated based on learner's answers (yes, no, no choice); generating rules are presented in Table 1. For example, if the car is at the entrance of the curve, the question prompted is "I was driving inside of the lane when I was turning" and the learner answers with either yes, no, no choice. After the learner answers all choice, by way of pressing an answer button, the system provides feedback as seen in Figure 6 (b) according to the stage in practice and results of the answer. Upon completion of each practice and review, if the instructor determines that the learner has mastered the selected step, the process moves on to the next step and repeats exercises similarly.

4. Related Works

Simulators are the most commonly used methods of teaching automobile driving as they can realize safe driving practice in virtual spaces as well as create various practice courses for learners (Leitão, J. M., Moreira, A., Santos, J. A., Sousa, A. A., & Ferreira, F. N., 1999; Backlund, P. et al, 2006; Wagner, J., Yao, Q., Alexander, K., & Pidgeon, P., 2013). Additionally, learners can drive repeatedly and safely in virtual spaces and game elements can also be incorporated. The ability to create different courses can allow several lessons for learners. Simulators merely mitigate the limitations of danger that can be experienced in actual learning, with the construction of a practice course and realization of accidents that could occur during driving. Learners can thus safely repeat traditional learning but must also understand and refine driving processes using their own ability. When using a simulator, the assignment of learning is to drive safely, exactly as it is with traditional learning in driving schools. Repeating this learning means that traditional learning is executed safely and efficiently. It is believed that a model for safe driving is implicit in this learning.

With regards to skill learning, the focus is often on correcting body movement (Iwasako, K., Soga, M., & Taki, H., 2014; Diedrichsen, J., & Kornysheva, K., 2015). If it is intended to speed up motion targeted for skill learning, correction of displacement of body motion is an important learning element. However, in activities where decision-making for action is crucial, as in this study, it is important to learn a model for prediction and map the model to real action (Endsley, M. R, 1995). Moreover, some researchers have pointed out that it is important to acquire knowledge for skills in skill learning (Stanley, J., & Krakauer, J. W., 2013).

Various types of information can be presented using HUD. In order to realize safe driving, lane departure misbehavior can be reduced by presenting the travel path of the car using AR (Tonnis, M., Lange, C., & Klinker, G., 2007). Similarly, warnings and indications of potential driving hazards are important technological advances linked to safe driving (Yang, Z. et al, 2018). The effects of displaying information and examining how it is displayed to the driver are being investigated. The presentations usefully equip the driver with information to recognize results of driving. However, polite presentation and partial automation (for example, automatically predicting and displaying dangerous behaviors) may conversely reduce the driver's cognitive ability. That said, it is extremely useful for emergencies, as well as to help the driver carry out appropriate driving.

There are many studies on learning support for driving practice aimed at making it possible for learners to safely repeat the vague problem of “How do you do the safe driving?” or easily increase variations of the practice course. Studies on skill learning have evaluated results of learner’s action, using myoelectric potential measuring instruments. The conscious problem that arises with these studies is focuses on making learners perform actions accurately and quickly. On the other hand, since most driving assistance systems are designed with the sole purpose of supporting only the driver and not the teacher, it is necessary that the driver understands enough about driving. In this study, the problem of car driving skill learning has shifted to "How do you do the cognition, judgment, operation and its cycle for safe driving". This change is much required. In the proposed system, by setting various constraints on AR, the learner is required to think not only about the operation but also the cognition, judgment, and its cycle. Therefore, this approach greatly differs from other studies.

5. Experimental Use

5.1 Procedure

Ten university students with driving licenses were selected as subjects. A driving simulator as seen in Figure 5 was used, with real car seats and dedicated controllers for the steering wheel, accelerator, and brakes. The HUD was located in the actual installation position, directly in front of driver. The school’s bioethics committee certified the experimental use of Gran Turismo 6 software for Play Station 3, which helped to create a more authentic driving environment. As a first step evaluation of this research, the purpose of this experiment was to verify if the exercise was meaningful for learning, at least for drivers who had already obtained a driving license.

Table 2
Questionnaire on the proposed driving practice administered to subjects

	Questions about the driving exercise
#1	Will the step by step flow of this driving exercise from System 1 → System 2 → System 3 → System 4 help you master curve driving?
#2	Will the step by step flow of this driving exercise from System 1 → System 2 → System 3 → System 4 help you master curve driving more effectively than conventional practice?
Questions on the operation practice function	
#3	Did the presentation on appropriate speed help you practice curve driving?
#4	Did the presentations on acceleration, deceleration, and appropriate speed judgment help you practice curve driving?
#5	Did the presentation of information on steering wheel operation help you practice curve driving?
Questions on judgment 2 practice function	
#6	Did the presentation of information on appropriate speed help you practice curve driving?
#7	Did the presentations on acceleration, deceleration, and appropriate speed judgment help you practice curve driving?
#8	Did the presentation of information on steering wheel operation help you practice curve driving?
Questions on judgment 1 practice function	
#9	Did the image of the curve shape help you practice curve driving?
#10	Did the displayed appropriate speed help you practice curve driving?
Questions on the reflection function	
#11	Do you think that reviewing your practice using the reflection function of this system will help you in mastering curve driving?
#12	Do you think that presenting driving improvements based on your practice review is helpful in understanding what you are not doing?

As part of the experimental procedure, subjects received an explanation on using the learning environment. Subjects were then required to drive a different course from the experiment in order to get accustomed to driving with the simulator, as it is a significantly different experience compared to driving a real car. After this practice, driving practice generally performed at Japanese driving schools was conducted on the simulator. The courses of different cities were used. An exercise using the learning environment was conducted.

Subjects then answered a questionnaire (summarized in Table 2) on the proposed driving practice. Q1 and Q2 related to learning methods used by the system, Q3 and Q4 related to the system's operation practice, Q6, Q7, and Q8 related to the practice of judgment 2, Q9 and Q10 related to the practice of judgment 1, and Q11 and Q12 related to the reflective method. If subjects positively answered questions, it would verify the proposed learning method and confirm that it deepens understanding as compared to conventional driving instructional and learning practice.

5.2 Results

As seen in Figure 7, subjects reacted positively to all questions relating to learning methods, confirming that this learning method is more effective than learning in driving schools. There were several negative answers relating to learning environment of operation and steering wheel operation. Subjects complained about visual issues due to the small size of the HUD and hard to see the tire angle. A similar problem was reported in relation to the practice of judgment 2. With regards to judgment 1, there were mostly positive answers. All subjects responded that the function of the reflective method was helpful in deepening their understanding of driving. It was difficult to confirm if any inertial force was experienced as this was a simulated exercise and subjects were looking through a digital screen and not the windshield of an actual vehicle. They judged from the driving screen of the simulator. About this reviewing, it is necessary to change the wording in the case of practicing on the simulator and in the case of practicing on a real vehicle. The learning method and driving models were well accepted by subjects. A better learning environment can be developed by refining the system based on these models and functions. Three subjects who were not confident about driving were interviewed, and it was concluded that understanding the driving cycle by the steps in this practice could alleviate their aversion to driving. Therefore, the learning method proposed and learning based on reflection could clarify assignment that were previously ambiguous for learners.

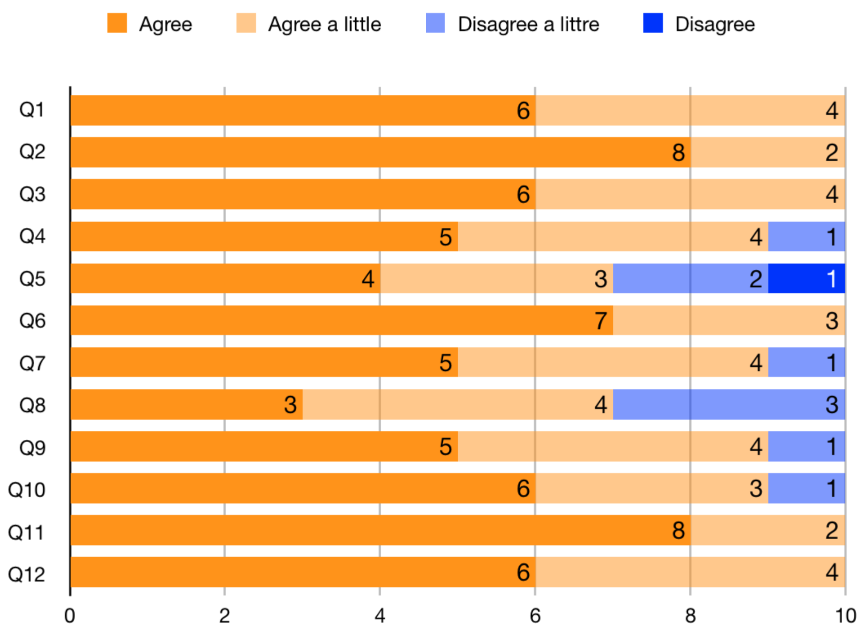


Figure 7. Results of the questionnaire.

6. Summary and Future Works

We developed a learning environment that can individually grasp the driving cycle of the curve, and evaluated its practical use. In Japanese driving schools, learners are given the task of correcting driving errors in order to realize safe driving. Driving is a cycle of recognition, judgment, and operation. However, as this cycle is continuously repeated in driving practice, it is practically impossible to actually learn cognition, judgment, and operation individually. We proposed a learning method to practice recognition, judgment, and operation individually and in fixed steps. For the realization of this system, we defined the model of curve driving and used AR. The study's purpose was to propose a change in the assignment from refining driving operation to individual learning of cognition, judgment, and operation and improved prediction ability for refining driving skill.

Experimental use of this system demonstrated that the proposed practice was more useful for learning driving than conventional driving schools, although it was verified in a simulation environment. This result is because the learner could learn the skills more clearly by redefining the question in learning of curve driving. It was also suggested that learners who were not good at driving could relieve aversion to driving by learning the process of driving more clearly. However, functionality needs to be improved as feedback was insufficient due to the simulation environment and technical difficulties viewing information displayed on the HUD. In the future, we will conduct more rigorous experiments with a larger subject size and consider similar learning in situations where prediction is more important, such as intersections.

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