

A Learning Module of Robot Programming for Elementary Schools: Based on Virtual Reality

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Abstract. Robot programming learning is an effective approach to developing 21st century learning skills. However, there are many problems in the learning practice of robot programming. Recently, teaching based on virtual reality (VR) has appeared as an effective method of robot programming teaching. Therefore, the current study examines the application of VR affordances in robot programming and provides a design of the learning module based on VR. The whole module is presented in 3 parts: needs assessment, media selection, and learning activities. The needs assessment part illustrates the needs, targeted learners, and learning objectives. The second part discusses and concludes why VR is suitable for robot programming learning and how it takes effect in the learning process. Ultimately, this third part provides the learning activities based on the discussion above. The learning activities are divided into 3 parts: robot lab, task classroom, and competitions. Each part takes advantage of specific affordances. These designs are aimed at facilitating learners' collaboration and construction. The theory of change is also analyzed in the conclusion. In addition to the content of learning objectives, better collaboration and construction are expected to be the learning outcomes.

Keywords: Robot Programming, VR, Affordance, Learning Design.

1. Introduction

In today's high-tech world, many new technologies are widely used in educational activities, such as the internet, virtual reality, augmented reality, etc [1,2]. Among them, virtual reality (VR) is a new practical and technological innovation in the 21st century. In recent years, VR is gaining a lot of attention in the domain of education. The 2020 Educause horizon report claims that VR is one of the six core emerging technologies and practices in 2020 [3]. VR provides virtual learning environments (VLEs) which enable more learning possibilities and potential learning benefits. There are many examples of VR application design in the domain of education. For instance, owing to its flexibility, effectiveness, and attractiveness, using VR in rehabilitation can offer specific benefits to both consumers and providers of services [4]. In the domain of biological education, proper interaction in the VLEs can motivate the learners and improve the learning effect [5]. Hannes Kaufmann et al. built a three-dimensional geometric construction tool to make the learning process easier and more encouraging [6].

In addition to the emerging technologies mentioned above, robot programming learning continues to rise in popularity. In many countries, robot programming education was introduced as an innovative curriculum in schools [7-11]. Especially the United States and Japan are in a leading position in robot education, which first carried out robotic courses in elementary or secondary schools early in the 1970s. Learning robot programming allows pupils to enhance their computational thinking and critical thinking, and improve their problem-solving skills, which support 21st-century learning skills in the digital age [9,11,12,22]. Moreover, robots are deemed motivating and engaging for learners. Robots are increasingly being incorporated into learning design as content and assistants, and are becoming an effective tool with which to motivate learners and enhance their learning performance [12].

Whereas, robot programming education has many problems so far. First, robotics courses are still not available for many students, especially in developing countries. For the reason that robotics courses are not included in required courses, only a small percentage of students can participate in

robotics competitions. Moreover, due to the pressure of competition results, teachers are concerned more about students' performance in the competition rather than their interest and information literacy [13]. Fundamentally, the shortage of robotics courses is the outcome of the lack of qualified teachers. More teachers and educational resources for robot programming are urgently needed. Second, robotics devices, which are usually provided by schools, require a certain amount of cost while individual students usually will not purchase or only purchase those simple robotics devices. The devices are developing and changing rapidly. Similarly, learners are always longing for the most up-to-date learning resources. As a result, limited resources are available. Besides, some learning tasks are outdated and not attractive enough. Fresh Stimulation and freedom of experiments are what learners need.

Compared with traditional teaching methods, robot programming learning based on VLEs has more advantages. Those problems above can be solved well in VLEs. Meanwhile, VLEs provide more benefits and better learning outcomes. Barney Dalgarno and Mark J. W. Lee elaborate on the characteristics of VR and conclude 5 affordances of VLEs which can be Summarized as spatial learning, experiential learning, motivation, contextualization, and collaborative learning. Well-designed VLEs based on these affordances can enable learning tasks [14]. First of all, VR can provide an immersive simulated environment and create embodied experiences that allow learners to learn efficiently. These affordances allow virtual robotics courses to maintain as in real life. Furthermore, VLEs can help teachers with their work content. Using VLEs to assist their teaching activities or as teaching materials makes the process more efficient. Thus, VLEs help to deal with the shortage of qualified teachers. Second, VLEs have fewer restrictions because of their characteristic of easy replicability. The learners don't have to prepare different parts of devices to achieve different functions. In VLEs, all they need to do is to install the software and download the resources provided online. Hence, abundant teaching resources are available. Third, VLEs allow for graceful failure. Many experiments are not allowed in real life because of the risk of damaging the equipment or posing a safety hazard to the user, which is encouraged in VLEs, such as short circuits and explosion experiments. Thus, VLEs have a huge advantage in protecting the natural curiosity of children. Last, VR has a great influence on motivating learners and encouraging communication [15]. There is a tendency to be active and communicate through verbal or non-verbal ways when in VLEs. Constructivism emphasizes that in relation to the recognition of an external object, "making" is more essential than "finding". Social constructivism claims that the main activity of knowledge formation is language and language-based intercommunication [16]. Hence, using a collaborative VR simulation to learn robot programming is a way of learning that matches the theory of social constructivism. Overall, VR has a positive effect on learning gains for K-6 students [17].

In this context, this research describes the affordances of VR and presents some learning strategies for VLE based on the affordances. This module aims to provide an environment in which the learners, especially the elementary students, can collaborate, learn robotics, construct and design efficiently. To achieve this purpose, social constructivism is discussed as the basic learning theory of the paper. And the module is a type of collaborative robot programming simulation. According to Liu, C. C., etc., collaborative simulation can promote engagement in collaborative learning [18]. With these affordances of VR and learning theories, a learning module is built and presented with needs assessment and learning activities.

Based on the discussion above, it can be seen that there is not a systematic understanding of how to use VR to learn robot programming yet. Hence, this article will review previous related studies and discuss the following aspects: 1. VR and VLEs. 2. Learning design.

2. Virtual Reality and Virtual Learning Environments

2.1. Affordances of VR

The concept of affordance was initially proposed in the direct perception theory of ecological psychology. Psychologist James Gibson elaborated that there are directly perceptible behavioral

relations between the creatures and their living environment. He concluded the relations with the term "affordance", which refer to all action possibilities with an object based on the characters' physical abilities [19]. Affordance is not a property of an object. It depends on the quality of the object, which is objective, and the capabilities and perceptions of the users, which is subjective. So, the scope of affordance spans both the objective and subjective domains. Thus, when discussing affordance, it is necessary to look at the medium itself in multiple dimensions as well as to relate it to users with specific characteristics in order to explore the possible connections that occur between them.

Subsequently, affordance was applied to many other domains, such as the domain of learning design. There are many pieces of research about the affordances of VR which deepened the understanding of VR and VLEs design. Barney Dalgarno and Mark J.W. Lee clarified five affordances of VLEs [14]. Their theory reveals some of the principal issues that need to be considered in the process of learning design.

First, VR technology is an effective means to provide the environment. In the 3-D virtual world, users are able to move around freely. Moreover, with VR controllers and gestures, some operations can be easier than with keyboards and game controllers. In detail, the interaction through keyboards often depends on the direction of the camera. The interaction through VR controllers has a higher degree of freedom. In other words, the interaction is not limited by the camera. Some delicate operations become easy to achieve. These determine that VR is a proper solution in relation to spatial skills and recognition.

Second, 3-D VLEs can be helpful to facilitate experiential learning that may be dangerous or difficult to achieve in the real world. For example, many physics experiments require an ideal laboratory environment that is impossible in the real world. The friction experiment requires a perfectly smooth surface to provide frictionless conditions. These requirements are easy to simulate in a virtual world.

Third, VR also has the affordance of motivating and encouraging. The high fidelity of the 3-D VLEs and natural world interface allows learners to mentally immerse themselves in the environment. VLEs put the learner into a situation to solve real problems. Besides, the learning process is often accompanied by Role Playing [20]. Hence, VLEs have the affordance of motivating learning and enhancing the learning experience. Especially when VLEs are combined with game design, there is a tendency that the effects are more significant.

Forth, VR supports contextual learning and facilitates knowledge transfer. VR technology can help provide rich perception and feedback. Therefore, creating learning environments through VR can help learners transfer what they have learned in virtual environments to real life.

Last, VR provides rich interactive means which facilitate collaborative learning. The avatar allows the users to communicate in non-verbal ways. When they adopt their role, the emotion is engaged, which can foster greater closeness within the group [14]. In other words, VR has the affordance to facilitate interaction between teachers and students, students and students, and students and the environment [20].

The above discussion supports the media selection in the section of learning design.

2.2. Learning Strategies for VLEs

Based on the previous discussion, this part explores the learning strategies for VLEs.

These strategies are not required learning strategies for the VLE. Based on the affordances mentioned above, a learning design that applies these learning strategies may facilitate student learning and take advantage of VLEs.

Also, it needs to be emphasized first that VR alone cannot influence learning outcomes. Proper strategies and good design are the most important. J. Garzón etc. indicate that those technologies have a medium impact on learning gains [21]. Their research also concludes that the pedagogical approach, the learning environment, and the intervention duration are what actually promote the outcomes combined with the technology. Besides, they state that the collaborative pedagogical approach has the highest impact. In conclusion, using technology to enrich the learning process is the key point.

Zone of Proximal Development. Vygotsky proposed the theory of zone of proximal development (the ZPD theory) which distinguishes between children's current and potential levels of development. The current level refers to the stable abilities which have been possessed. The potential level implicates the abilities which can be achieved with guidance and are close to the current level. In intellectual activities, there may be a difference between the problem to be solved and the original ability. Through the learning process, learners can eliminate this difference. This difference is the zone of proximal development.

Scaffolding instruction, one of the learning strategies stemming from the ZPD theory, helps the learners climb up. In collaborative learning, the partners act as part of the scaffold. The learner with higher ability can give effective help to those with lower ability. In fact, the activity is not unidirectional. Instead, it is bidirectional since learners learn from each other and from different aspects. Thus, collaborative learning naturally has a multidimensional scaffold. Combined with a scaffold provided by an explorable environment and, most importantly, the scaffold designed for different learners, the learning process in VLEs can be more effective.

Proper learning objectives can be set up based on the design of the zone of proximal development. Subsequently, the ZPD theory provides guidance for further design of learning strategies. Relying on well-designed activities and learning partners, a learning module on the basis of the ZPD theory can effectively guide learners toward the targeted learning goals.

Social Constructivism. Social constructivism mainly comes from Vygotsky's theory of psychological development and the theory of cultural and historical development. Social constructivism considers learning as a social process and emphasizes the role of communication and social activities in the development of people's advanced psychological functions. It claims that the main activity of knowledge formation is language and language-based intercommunication.

Owing to the affordances mentioned in 2.1.1., VLEs are good at building up group relationships and allowing learning activities mainly based on social constructivism strategy. Good group relationship contributes to the process of construction and communication, which also benefits the construction. On the flip side, construction contributes to the relationship and communication as well. Thus, the learning in VLEs can be collaborative, with a well-designed scaffold and has a high degree of freedom.

3. A Learning Design of Robot Programming

3.1. Needs Assessment

Analysis of Learners. The targeted learners are pupils which are between the age of six and twelve.

First, learning robot programming is consistent with the cognitive development of pupils. Pupils are in the concrete operational stage. Therefore, they tend to learn abstract programming languages based on concrete items. Conventional programming learning that relies only on console applications is not in line with children's cognitive development. On the contrary, robots can provide concrete objects for programming. Therefore, learning robot programming is an effective tool to learn programming and develop related thinking skills.

Second, learning robot programming is an effective means of developing many thinking skills. When learning robot programming, learners always work in groups, explore the possibilities of programming, make their own designs, and solve problems. When using technology tools to solve problems, computational thinking is often a mode of thinking that is required in the process. So, designing and programming robots can exercise learners' computational thinking. Meanwhile, many other thinking skills are required and exercised in the process, such as logical thinking skills, practical skills, hands-on skills, technological literacy and thinking skills, innovation, and team spirit. The relationship between these thinking skills and programming has been confirmed in many studies. Further, according to L. Sun, etc., 4th grade is a crucial period of the development of computational thinking skills [23]. So, it can be efficient for pupils to learn robot programming and develop their thinking skills. It is important to note that the capabilities of robotics programming are not entirely

age-dependent, many adults have never accepted robotics programming education. Hence, those learners who are interested in robotics can use this learning module as well. These learners can easily take robotics courses at home and access a wide range of learning resources by using this module.

Third, robot programming, an emerging course, follows the trend of the generation. Meanwhile, computational thinking, one of the most important thinking skills in the information age, is being pursued by learners and studied by educators. The enthusiasm for robot programming continues to grow, and the demand for robot programming teachers is becoming ever greater. However, in many countries, the availability of robotics courses needs to be improved. The popularization of robot programming courses faces many obstacles. High-quality robots kit is expensive and often sell for thousands or even tens of thousands of dollars. Many families do not choose to purchase high-quality robot kits because they can only be used for learning robot programming, and organizations such as schools have limited devices to purchase and provide to students. Additionally, there are some visual programming tools and the majority of them require devices in the real world. Further, there are some robot programming games. But most robot programming games lack communication. Or the majority of them are made for a specific domain, such as corporate training. Well-designed learning modules for robot programming are needed.

Analysis of Content and Context of Use. The subject matter area is robot programming. The content is based on information technology textbooks for elementary students. Creative workshops can also be included in subsequent development to encourage users to make their own robot models and upload them.

The context of learning is informal. It is suitable to apply this module both at home and in extracurricular activities. The design of this module hopes that learners can learn easily and comfortably, actively construct knowledge through exploration, entertainment, and communication, and implicitly acquire development. Therefore, this module is designed for informal settings. If it is to be used in formal teaching, it needs to be supplemented with more details of instructional design and learner-specific analysis.

Analysis of Learning Objectives. This module has 4 learning objectives:

1. To understand how robot programming is working
2. To design and program for robots based on specific problems or goals
3. To have an interest in robot programming
4. To develop the computational thinking skills

The 1st and 2nd objectives are procedural objectives. The 3rd is attitude objective. The 4th is a literacy level objective. These objectives are designed especially for pupils. Learners with a higher level of capability need different objectives which depend on the actual situation. Also, the objectives need to be adapted to the individual learners and more detail is required according to the situation.

3.2. Media Selection

The best way to learn robot programming is not by reading or watching. A better way is working in groups and solving problems. The learning approach can be concluded as these 4 parts:

1. Explore
2. Communicate
3. Collaborate
4. Construct

It demands an immersive environment where the learners can explore and do experiments. This requires the affordance of “immersive”. Further, it demands an interactive system that group members can communicate and collaborate. This requires the affordance of “interactive” and “social”. Besides, robot programming involves both robot devices and programming tools on pc or mobile platforms. The operation of the robot requires a specific solution that is more flexible than keyboard operation. This requires the affordance of “spatial” and “interactive”. Finally, a system with those ingredients tends to be helpful to social construction. Considering pupils are curious by nature but easy to lose

patience, the affordance of “motivating” is essential as well, which can be provided by the game mechanic design and the VLEs design.

Thus, combined with the discussion of affordances in 2.1., VR game matches all the affordances and occurs as proper media. This media selection requires the learners to prepare VR goggles and related devices.

3.3. Design of Learning Activities

The learning activities will follow the learning strategies of the VLEs. Social constructivism is the main learning strategy. The interaction is simple enough for pupils or beginners. In this module, the learners can interact by using VR controllers or gestures. During the whole learning process, they can work in groups and solve problems. Problem-solving is an efficient way of learning procedure knowledge. Problem-based learning encourages learners to move on and communicate. Communication between groups happens in two kinds of ways. With a microphone or text, communication achieves in verbal ways. Meanwhile, the avatar allows the learners to communicate in non-verbal ways. So, the module encourages communication and construction in the VLEs.

The learning activities can be divided into 3 parts:

1. Robot lab
2. Task classroom
3. Competitions

In the robot lab, the learners can use the available devices to build and invent, do experiments to explore, and figure out the methods to achieve certain functions. In the beginning, not all the devices are available. The users have to complete tasks in the task classroom to unlock the robot devices. Robot lab allows learners to release their curiosity and construct without being afraid of danger or limitation.

In the task classroom, the learners need to complete some tasks. Then, they can receive permission for a robot part, such as a robot arm. This mechanic helps encourage and motivate the learners. Looking specially at the tasks, they will be unlocked in turn. Only the tasks that are in the zone of proximal development will be shown. Scaffolds are provided when the learners have difficulty completing the tasks without guidance.

In the competitions, the learners compete with other groups. The competitions can be measured from different dimensions. This part brings competitive and playful ingredients into the module.

These three sections are designed to correspond to the learning objectives and should not be viewed in isolation or with emphasis on only one of them. They do not correspond one-to-one. Each activity contains the learning objectives of these four dimensions. The three activities can cooperate with each other to complement each other's strengths and weaknesses.

Since the learning context is informal, the learning process does not have an exact point to end. The learning comes from collaboration and construction. The process is continuous and the development continues even after the end of the process due to the development of computational thinking literacy.

4. Conclusion

Through discussing the five affordances of VR and learning strategies for VLEs, this article argues that VR is suitable as the media for learning robot programming and provides a learning module.

This paper discusses the demand for educational resources of robot programming and the design process and details of this learning module. Learning robot programming, which helps to improve children's computational thinking, critical thinking, and other important thinking skills, is an important curriculum for elementary students. However, most students have limited access to robot programming courses due to the lack of faculty, robot kit equipment, teaching resources, and so on. Thus, a robot programming learning module based on VR is designed. First, a detailed needs assessment was conducted by identifying the learning needs, learners, and learning objectives. Then,

by analyzing the learning approach and affordances, VR is selected to be the media for robot programming learning for elementary students. At last, three learning environments are provided based on the above analysis, and coherent learning activities were designed. These discussions can also serve as a reference for other VR-based learning designs.

This module takes advantage of the affordances of VR to facilitate learning activities. Since VR has spatial affordance, it makes the operation and observation easier in the VLEs. So, the learning process can be more effective. The learners can have access to richer learning resources. Meanwhile, VR has social affordance. Both verbal and non-verbal communication will be easy, which supports learners' collaboration and facilitates the construction of knowledge. Moreover, VR games can motivate learners and make them feel motivated and want to move on, which makes them more active and become interested in robotics. In general, the learning module of robot programming based on VR affordances makes learners change in the planned direction through the learning process.

Nevertheless, there are some limitations in the current research. First, the targeted learners in this study cannot cover the situations in all countries and areas. Although VR goggles can be much cheaper than most high-quality robot kits, students in many countries, especially in developing countries, will still feel burdened. Further, this study designs the learning module but does not conduct learning practice to empirically prove and improve it. More details of learning activities are needed through practice and further research. Finally, to provide better scaffolding, more detailed segmentation and individualized assessment of learners are expected. As well, if the model is applied to a formal teaching and learning environment, more detailed assessment assistance is needed, and the actual teaching and learning assessment should depend on the specific reality and be further completed by educators. In summary, subsequent research could focus on a more visual, multidimensional assessment of learning or work on assisting a broader range of learners.

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