# Consistency in Multi-device Service including VR : A Case Study

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**Abstract.** Nowadays, we have entered a world of multi-device experiences. This phenomenon poses a significant challenge because we have to deploy applications to different platforms, with a consistent UX for each targeted device preferably. Consistency provides users with a stable framework in similar contexts and helps to improve multi-device usability. Many previous studies focus on maintaining consistency among traditional platforms like smartphones apps and websites. However, with the rapid development of VR, it is crucial to add it to the spectrum because the design for VR differs from that for traditional 2D screens a lot. Therefore, this paper proposes a series of design principles to ensure the consistency across multiple devices including HMD-VR, along with four dimensions of consistency worth considering. We use *Virtual Experiment of Film Language*, a multi-device serious game as an example. Twelve participants were recruited to experience the VR and WebGL versions of the game to spot inconsistency issues. After that, the game was modified according to the survey results and evaluated by the participants again. The evaluation result showed that consistency was improved. We proposed three consistency design principles based on our findings. They can help multi-device applications improve consistency across devices so as to enhance inter-usability and user experience.

**Keywords:** Consistency, Multi-device, Virtual reality

## 1 Introduction

Nowadays, we are surrounded by all kinds of digital devices, from smartwatches, smartphones, tablets, PCs to the rapid developing VR devices like HTC VIVE and Oculus Rift. According to Cisco's report, global mobile devices and connections grew to 8.6 billion in 2017, and will grow to 12.3 billion by 2022 [1]. We have entered a world of multi-device experiences and our lives are full of interactions with them, which leads to an ecosystem of connected devices.

The diversity of consumer computing platforms has become an everyday fact nowadays. It is not rare to see users performing their tasks across various devices with various multi-modal interaction resources. This phenomenon poses a significant challenge because we have to deploy applications to different platforms with suitable UX for each target device. Individuals react to objects and events based on previous experience from similar situations. Thus, it is important to maintain consistency across multiple platforms for the sake of user experience. This study focuses on the multi-device environment, the service aims at sequential (asynchronous) use and cross-platform, as defined in [2], which means that a single application can be experienced on multiple devices and each device has complete functionality and is able to offer the entire experience on its own. Meanwhile, users only use one device at a time and do not switch between different devices frequently. This study follows the consistency design approach defined by Levin [3]: the same basic experience is replicated between devices, keeping the content, flow, structure, and core feature set consistent across the ecosystem.

Consistency is important because it reduces the learning cost, helps to eliminate confusion, and also reduces development cost. It provides users with a stable framework in similar contexts and can help to improve multi-device usability. Nevertheless, maintaining consistency across various devices is an open issue. Some studies show that consistency is a crucial factor for multi-device experience. Many of them focus on common digital media like smartphone apps and websites, but with the rapid development of VR, it's important to take it into consideration.

Virtual Reality offers an immersive experience that closes out the physical world in which users can be transported into various virtual worlds rich in content. Stereoscopic vision, spatial sound, haptic feedback are all fundamental factors to consider while designing the VR experience, which differs from designing for 2D screens considerably. Thanks to her unique advantages, VR plays a vital role in the field of education [4]. For example, the VR version of *Virtual Experiment of Film Language* [5], a serious game that allows users to learn film language in VR, provides an immersive and efficient learning experience, but not everyone can access VR devices at any time. Therefore, it is valuable to propose a systematic solution featuring a multi-device experience. In this way, learners can enjoy a similarly immersive and efficient learning process whenever and wherever needed.

This paper proposes a series of general design principles to ensure the consistency of multi-device experience. We specifically care about how to maintain design consistency between HMD VR and desktop applications. The content is organized as follows: We reviewed various state-of-the-art studies in in Sect. 2 and brought forward four dimensions of consistency in Sect 3. And then in Sect. 4, we describe the case study and our proposed consistency design principles. Finally, in Sect. 5, we discuss the achieved work and provide some suggestions for future work.

## 2 Related Work

### 2.1 Concepts of VR And Serious Games

Nowadays, VR technology has been widely recognized and used in many industries to support decision making and enable innovation [6]. Design for VR is difficult due to the lack of concrete design guidelines and examples [7] mainly because VR has many features that differ from traditional platforms. Many VR devices include optical or ultrasonic tracking systems to calculate physical objects' position and orientation in real-time, which makes gesture-based interaction in VR possible [8,9]. Most VR devices also have handheld controllers that allow users to navigate and manipulate objects in the virtual world [10]. Force feedback and vibration are provided by haptic devices [11]. Audio in VR is usually supported by a fully surround sound system which enables sound localization.

A serious game is one designed for a primary purpose other than pure entertainment. There has been much research combining VR and serious games with some success [12-14]. Henrikson et al. proposed a workflow, specific to the needs of professionals creating storyboards for VR film, and presented a multi-device (tablet and head-mounted display) storyboard tool supporting this workflow [15]. Moreover, it is worth noting that they try to ensure consistency by making the tablet and the VR system display the same FOV(90°) and let both interfaces contain a ground plane represented by a radial grid and a degree scale wrapped around the environment for orientation. Vara et al. found that the type of device could be an important variable in serious game efficacy [13]. Furthermore, Longo et al. presented an innovative multi-device application based on the concept of intelligent serious games and studied the usability and sense of presence provided by different devices [14].

### 2.2 Multi-device Consistency

One challenge for interaction designers is to meet the requirements of consistency and continuity across these platforms to ensure the inter-usability of the system, namely the usability and user experience across the different user interfaces of a given system [16]. However, the "design-once-run-everywhere" strategy [17] does not apply for the current market.

Many previous studies focused on how to maintain consistency among traditional platforms like smartphone apps and websites. Lee et al. found that consistency showed a more significant effect on usability and credibility [18]. Sun et al. argued that there were three key object-based beliefs about consistency, namely information consistency, system consistency and service consistency [19], and investigated the standardization–adaptation paradox during the web–mobile service transition [20]. Majrashi et al. found that inconsistency was a principal factor affecting task continuity when participants switched from and to mobile native applications and mobile websites [21], especially when task complexity was sufficiently high [22]. Segerståhl and Oinas-Kukkonen found that the symbols, terms and interaction logic should be as consistent as possible between interaction devices to improve the semantic coherence, which contributed to user experience [23].

Oliveira and Rocha proposed consistency priorities to support multi-device interface design, and they suggested applying consistency on multi-device contexts using the following priorities: *Task Perception*, *Task Execution* and *Task Personalization* [24]. Dong and Wan presented a systematic method for the consistent design of user interaction which focusing on the consistency of logical interaction rather than physical or visual interfaces [25]. Hajdukiewicz et al. argued that content critical to task completion, performance, and behaviour-shaping constraints that users attuned to needed to be consistent in form across platforms, while secondary and supporting information not critical to shaping behaviours did not need to be consistent (but certainly could be if appropriate) [26].

Denis and Karsenty argued that seamless transitions between devices required both knowledge continuity and task continuity, which required inter-device consistency addressed on four levels: *Perceptual*、*Lexical*、*Syntactical*、*Semantic* [27]. Wäljas et al. proposed a framework in which consistency could be leveraged through *perceptual* (look and feel), *semantic* (symbols and terminology) and *syntactic* (interaction logic) consistency [28]. S´anchez-Adame et al. presented their five design guidelines to maintain consistency in multi-device systems include *Honesty*、*Functional Cores*、*Multimodality*、*Usability Limitations*、*Traceability* [29].

All these works show that consistency in multi-device service is a significant field with many open issues to explore. Although there is a lot of existing research on keeping user experience consistent, there is a lack of theoretical framework. Moreover, the devices considered in the consistency research only include traditional platforms like cell phones and PCs, the latest VR devices are not considered, so there is an urgent need for further exploration.

## 3 Dimensions of consistency

Basing on the review of various works on consistency, we present four dimensions of consistency to consider when designing multi-device applications:

- Semantic consistency: multi-device applications shall have the same core content and functionalities across devices. Services provided shall be similar across devices by the definition of the consistency design approach.
- Syntactical consistency (interaction logic consistency): to complete a given task, the same set of operations or steps shall be required across devices; the user can achieve the same result regardless of input and output modalities.
- Perceptual consistency: the overall visual appearance, basic information structure and organization shall be consistent; multi-device applications shall look and feel similar on different devices.
- Lexical consistency: multi-device applications shall use the same set of vocabulary and symbols across devices.

Of course, the most important consistency is about user expectations [30]. The more important an element is in a multi-device application, the more consistent it shall be with users' expectation.

## 4 Case study

This section describes a case study to put the proposed consistency dimensions into practical use to spot inconsistency issues and guide the modification of an existing application to enhance its consistency and usability. Preliminary consistency principles for multi-device application development were concluded as the outcome.

### 4.1 Introduction to the test material and experiment procedures


**Fig. 1.** The interface of the web version of The Virtual Experiment of Film Language

The test material we used was *Virtual Experiment of Film Language*, a multi-device serious game that allows users to learn film language in virtual space and provides an immersive and efficient learning experience. It has two different versions: a desktop version embedded in a webpage as a WebGL program(see Fig. 1), and an HMD VR version running on HTC Vive Cosmos (see Fig. 2). We focused on the shooting and editing stage of this serious game because it is the most complex part of the whole learning process, which involves a lot of interaction. In the shooting stage, the user can freely shoot in the virtual environment by using the Vive controllers as a virtual camera in the VR version. Correspondingly, a user may fall back on keyboard and mouse to translate or rotate the virtual camera in the desktop version. In the editing stage, the user can go to the playback mode at any time to review what has been recorded and reshoot the unsatisfying parts. The main differences between the two versions are listed in Table 1.

**Fig. 2.** The VR version of Virtual Experiment of Film Language

12 participants were recruited to experience them and report how they thought about the consistency issue between two versions individually. We informed them to pay attention to the consistency dimensions mentioned above to provide them with a structure of thinking and to prevent them from being distracted by other design aspects. We chose the participants with backgrounds in HCI and interaction design because of their acquaintance with our research topic. Many of them reported inconsistency issues in the four dimensions after they used both of them for the first time.

**Table 1.** The main difference between the web and VR version

| Main Difference | WebGL version | VR version |
|---|---|---|
| move camera | use gizmo or keyboard | move one' s body and right hand |
| start shooting | click the red button | keep pressing the right trigger |
| pause shooting | click the red button | loosen the right trigger |
| check camera view | click the camera view button | press the right trigger |
| adjust the focal length | drag the slide bar | push the left joystick up or down to adjust FOV |
| change camera mode | N/A | click the right joystick |
| change current time | click on a point on the timeline | press the left trigger and use right joystick and trigger to manipulate timeline |
| call for help | click the help button | voice help at the beginning |
| initial position | same height as avatar | same height as the second floor |

Then, this serious game was redesigned by us with the knowledge of their feedback and the theories on consistency. On completion of the modification, we asked the participants to evaluate the revised version again. The general feedback was more positive, showing that both consistency and usability improved.

### 4.2 Issues and solutions

According to our participants' feedback, this multi-device serious game's consistency is good enough concerning semantic and lexical consistency. The participants are clear about the purpose and content of the game. As for semantic consistency, they know what they need to do and what they can expect in the game. In terms of lexical consistency, in general it is OK. The only exception is the terminological difference between the two versions: the *focal distance* as called in the desktop version was measured using FOV in the VR version. We fixed this by changing the VR version and using focal distance in both of them.

**Syntactical consistency.** One of the most frequently mentioned issue of inconsistency is that the feeling of film shooting differed a lot between the desktop and VR versions. The desktop version felt like creating a movie clip in DCC software such as *blender* or *Maya* in which one has to use a gizmo to translate and rotate the camera from time to time. In contrast, the VR version's shooting felt more natural and realistic because the camera movement is bind to one's right hand's movement. We thought the inconsistency arose from the different level of operation directness between desktop and VR experience. Some participants reported that they were fond of the FPS-game-like control of the camera which allowed them to control its movement directly (see Fig. 3.). In contrast, others claimed that to move and rotate the camera with a gizmo gave them more accuracy, so they prefer using the gizmo. So we decided to keep both of them and make the FPS control scheme as the default one in the desktop version. There might be other control scheme capable of offering higher level of directness for desktop applications, say using data from the sensors of a mobile phone for camera control. But since we hoped that the desktop version kept simple and easy to use, these complex schemes were not implemented in this study.

Another inconsistency problem arose from the inconvenient timeline controls in the VR version, which was more serious because it changed our participants' behaviour patterns a lot. Many participants were found to move back and forth on the timeline a lot using the desktop version to remake some shots. However, as for the VR version, they tended not to enter playback mode to use the timeline due to the inconvenience of switching between two interfaces. Consistent elements should work in the same way between devices. The solution was that we enlarged the VR version’s camera view to 160% and thus the timeline was more visible and could act as an indicator of the progress of the shooting. Furthermore, we allowed the user to manipulate the timeline directly by pushing the joystick on the controller to the left to step back by a frame and to the right to step forward by a frame. In this way, the timeline manipulation in VR was more direct and more consistent with the desktop version subjectively.

Sometimes the control method is a compromise between directness and accuracy. The desktop version was more straightforward and convenient as far as timeline operations were concerned, while the VR version was more straightforward regarding camera movement. Nevertheless, through careful thinking and innovative design, we can minimize the gap to an unnoticeable extent.


**Fig. 3.** The first-person view of the web version

**Perceptual consistency.** The most significant inconsistent issue was that the information provided by these two versions was different in quantity and modality. The VR version did not use a GUI to provide information or functions while the desktop version relies heavily on many UI elements on the screen to provide functionality. The VR version did not use a GUI because we hoped to reduce the learning cost as much as possible by making the interface minimal, Also, we did not want users to be distracted by GUI. Another reason was that the resolution of contemporary HMD displays, for instance the HTC Vive Cosmos we used in our experiment, was not very high and normal GUI designs for desktop would be difficult to read comfortably. However, when compared with the desktop version the inconsistency of the VR version's lack of GUI and the inconvenience caused by it became unneglectable to many users. As shown in Fig. 1, the GUI in the desktop version not only indicated the progress of the game but also provide various functions including help, zooming in and out, start and stop recording and so forth. In contrast VR version kept a user informed of the progress with vocal instructions, the operations were explained once using figures shown at the center of the viewport at the beginning, there was no other GUI elements except for a small LCD screen at the upper left corner with a tiny progress bar attached at the bottom, to showing the user what the camera was seeing during the shooting.

*Different amount of information.* One of the inconsistency issues came from the different amount of information accessible to a user at the same stage in two versions. For example, in the desktop version, a user could check and change all the important parameters of a real-world camera in the shooting stage, such as aperture size, ISO value and the focal length. However, the VR version hided all these from the user in the same stage. Another example was the help information. In the desktop version, it was detailed and accessible at anytime, but in the VR version one could not review it after the introduction at the beginning. These differences made participants feel inconsistent, especially if they experience the desktop version first and the VR version later.

Our solution to this problem was to add a world space UI to the VR version that kept floating around the camera and showed all the important parameters in it. Users might change these parameters with their right hand controller easily. Moreover, we designed a camera space UI which the user could call out at any time by pressing the grip button (see Fig. 4). This solution improved not only consistency but also usability of the VR version according to our interviewees.

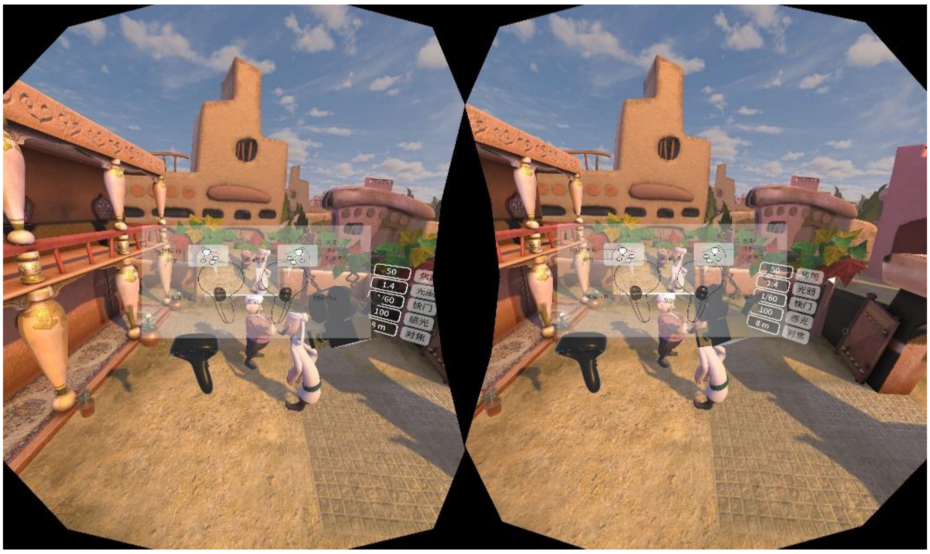


**Fig. 4.** The help menu UI, enlarged camera view and camera information UI

*Modalities.* Another problem related to the previous one was that some information, like the operation instructions, was sent to the user via different modalities in the two versions. Many participants reported that they could not remember the vocal instructions well in the VR version, and they preferred the desktop version which conveyed the help information.

We assume that the effectiveness of different modalities affects consistency here. Therefore, important and complicated information shall be delivered to the user in the same way or in a similarly effective approach. We turned most of the vocal instructions that taught a user how to shoot into visual information in camera space GUI as described above. However, for simple information, modality consistency seemed less important. For example, in the desktop version, we used on-screen label to let a user know whether he/she was shooting, editing or reviewing the film while this information was delivered using a vocal reminder playing only once. However, no participant complained about this inconsistency because this information was clearly understandable and straightforward so it did not matter whether it was received by seeing or hearing.

Interestingly, we spotted several inconsistency issues that may not need to be addressed according to the survey. For example, the actions to start shooting were different: in the desktop version, a user needed to click the big red button on the right bottom of the screen, while in the VR version one had to keep pressing the right-hand trigger button. Although many participants tried to press the trigger button once shortly to start shooting because of the mental model affected by the desktop version, but they would soon find out the correct way of operation by themselves and began to love this feature only found in VR as it allowed more accurate control on timing and made users feel like they were really shooting a film. In this case, the consistency rule was altered but not broke. It was a compromise because it obviously unwise to force a user to press and hold down the record button in the desktop version to shoot continuously, which would undoubtedly lead to clumsy operations and worse user experience.

### 4.3 Design principles

After the experiments were completed, we summarized three design principles based on our findings to guide future design practice of multi-device applications including VR:

- Interactive operations in different media shall be similar as far as logic and procedure are concerned. Under this premise, we shall design them to be as direct and easy to use as possible.
- The amount of information or content obtained from a given task/stage should be as equal as possible, especially for the important information critical to task completion, performance, and behaviour-shaping.
- System output should be independent from input modalities and platforms. For important outputs critical to shaping crucial behaviours, the output modalities shall be same or at least same in effectiveness. Secondary or auxiliary outputs do not need to have the same modality across different devices.

These principles place emphasis mainly on syntactical and perceptual consistency rather than semantic or lexical consistency. The first principle is specially suitable for VR interaction by taking into account the fact that some operations in VR are more straightforward. We see no reason to give up the advantage of this fact in the case of VR for the sake of consistency. The benefits of VR should be maintained while interaction for other devices should be devised carefully to be as direct and easy to use as possible. The second and third principles are a bit more general but also very helpful to consistency. If a user cannot have equally easy access to the same amounts of information at a given step, he will feel confused and fail to feel or benefit from the consistency between them.

## 5 Conclusions and Discussion

The main contribution of this paper is a series of design principles for the sake of consistency across different devices including VR HMDs. It also brought forward four dimension of consistency to be use as a guideline for consideration.

The four dimensions of consistency need to be further addressed. Some of our findings suggested that we shall pay more attention to the consistency of logical interaction rather than that of physical or visual interfaces. However, other findings suggested that same look and feel (perceptual consistency) is critical because it determined the user's first impression of the application. More research is needed to clarify the meaning of consistency and the user mental model so that the four dimensions of consistency can be sorted according to their significance.

As mentioned above, we found that the modifications we made according to these principles not only improved consistency but also enhanced usability. Besides obtaining benefits directly from improved consistency, a reasonable assumption is that the process of considering how to maintain multi-device consistency itself prompted us to think about our design from more perspectives. For example, we inspected many different input and output modalities while we were reviewing the original design. In this way, our mindset broadened and thus the overall design quality improved as a result.

We hope that the proposed consistency design principles, for UX designers, will reduce the complexity of designing multi-device applications, and for users, it will contribute to with the availability of products of great consistency and usability, easier to learn and to use.

In the future, the proposed design principles are subject to further revision while we redesign the user experience of this serious game for more kinds of digital devices such as mobile phones, tablets and other kinds of XR devices. Besides, more applications ought to be measured and more practice shall be carried out under the guidance of these consistency principles so as to validate them with prototypes. Secondly, a consistency assessment method should be developed to evaluate the level of consistency quantitatively so that the conclusions will be more objective. It will also help us to have a better understanding of how these factors contribute to each other. Thirdly, we encourage you to conduct a comparative study between our proposed design principles and another set of similar principles to determine its value based on their actual performance in design practice.

There is still much more research to be done in the area of multi-device consistency. Hopefully, our work may serve as a pilot explorative study in this field.

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