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# TASK ANALYSIS AND DOMAIN MODELS IN DESIGNING VIRTUAL ENVIRONMENT OF A WEB-BASED NON-IMMERSIVE VIRTUAL ENVIRONMENT APPLICATION (WEB-NIVEA) FOR DIAGNOSING DYSLEXIC CHILDREN' POTENTIAL

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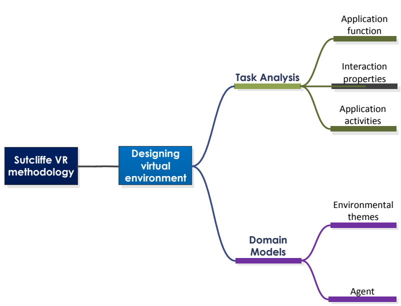
## Graphical abstract




## Abstract

Virtual reality (VR) technology has novel, complex attributes such as realism and immersion that far surpass 3D multimedia applications, thus entailing appropriate development methodologies. In this study, the researchers propose a new development methodology based on the adaptation of Sutcliffe's VR development methodology in designing a diagnostic tool called *Web Based Non-Immersive Virtual Environment Application* (WEB-NIVEA), which would be used as a tool to diagnose dyslexic children's potential in visual spatial field. The development of WEB-NIVEA was based on tasks analysis and domain models phases. Specifically, the analysis of task phases focused on three sub activities, namely application functions, interaction properties, and application activities. In tandem, the analysis of the domain models helped the design and development of the tool using relevant environmental themes mediated by a virtual agent. To add a sense of presence, realism and interaction elements were employed to engage potential users, especially dyslexic children, to use this tool with ease and fun. Through heightened engagement, dyslexic children can diagnose their potential, so that appropriate learning path can be identified and enhanced to help these children learn efficaciously, thus helping them to embark on suitable careers later in their lives.

*Keywords:* Non-immersive virtual reality, virtual environment, web-based application, diagnostic tool, dyslexic children

## Abstrak

Teknologi realiti maya (RM) yang memiliki ciri-ciri unik dan kompleks seperti realisme dan immersif yang berbeza berbanding dengan aplikasi multimedia 3D, telah membawa kepada keperluan metodologi pembangunan yang sewajarnya. Dalam kajian ini, penyelidik mencadangkan metodologi pembangunan baru berdasarkan adaptasi metodologi pembangunan Sutcliffe RM dalam mereka bentuk alatan diagnostik yang dikenali sebagai *Web Based Non-Immersive Virtual Environment Application* (WEB-NIVEA) untuk mendiagnosis potensi kanak-kanak disleksia dalam bidang visual spatia. Pembangunan WEB-NIVEA adalah berdasarkan kepada fasa analisis tugas dan juga model domain. Secara khususnya, fasa analisis tugas memberi tumpuan kepada tiga sub aktiviti, iaitu fungsi aplikasi, ciri-ciri interaksi dan aktiviti aplikasi. Selaras dengan ini, analisis model domain membantu merekabentuk dan pembangunan alatan diagnostik ini dengan menggunakan tema persekitaran yang bersesuaian dengan bantuan agen maya. Untuk mewujudkan perasaan immersif, elemen realisma dan interaktiviti telah digunakan untuk melibatkan pengguna yang berpotensi terutamanya kanak-kanak disleksia menggunakannya dengan mudah dan menyeronokkan. Melalui penglibatan yang tinggi, kanak-kanak disleksia boleh mendiagnosis potensi mereka yang mana dengan ini laluan pembelajaran yang sesuai dapat dikenalpasti dan seterusnya dapat membantu mereka belajar dengan berkesan. Justeru, mereka dapat memilih kerjaya yang sesuai pada masa akan datang.

*Kata kunci*: Realiti maya bukan immersif, persekitaran maya, aplikasi berasaskan web, alatan diagnostik, kanak-kanak disleksia



## 1.0 INTRODUCTION

Virtual Reality (VR) technology is widely used in various domains such as education (Chen, Yang, Shen, & Jeng, 2007; Kovárová & Sokolský, 2011; Rahim et al., 2012), medical (Bruce & Regenbrecht, 2009; Gopalakrishnakone et al., 2011) , commerce (Barnes, 2007; Nassiri, 2009), and entertainment (Pakanen & Arhippainen, 2014). However, the use of VR technology in psychometric testing or aptitude testing is very limited. Psychometric testing is an important part in psychology; for example, it is routinely used as an aid to diagnose children's potential at the early stage of learning. According to Gagne (2009), for children to become talented individuals, they must undergo a systematic process of transformation. Realizing the desired transformation entails an early, accurate diagnosis of children's potential, especially those with learning disability such as dyslexic children, so that appropriate learning paths can be identified and enhanced to help these children learn efficaciously, thus helping them to embark on suitable careers later in their lives.

Many studies have shown that dyslexic individuals, despite having learning disabilities, do possess a diverse range of potential (Tafti, Hameedy, & Baghal, 2009; Assouline, Colangelo, & Ambroson, 1994; Bacon & Bennett, 2013; Cooper, Ness, & Smith, 2004; West, 2003). Notably, based on a conference consensus reached by a group of researchers (West, 2003), dyslexic children tend to exhibit a unique ability – visual spatial (VS) skill. VS skill is an important ability required in many important fields, such as engineering, architecture, and astronomy, as well as other technical fields (Eide & Eide, 2011; Lubinski, 2010; Samsudin, 2011; Samsudin, Rafi, Mohamad, & Nazre, 2014). A review of the current literature by the researchers revealed that the focus of most studies was almost exclusively on learning (Davis & Braun, 2010; Eide & Eide, 2011; Gilger, 2012; West, 2003) – in fact, very little research focusing on talents has been carried out. Further compounding this situation, a majority of the computer-based tools used for psychometric testing are two-dimensional (2D) and generic, precluding effective, accurate measurements of talents. Premised on these drawbacks, several researchers have recommended the use of more potent technologies, such as desktop VR technology, to improve the diagnosis of children's talents compared with current, conventional methods (Cohen & Hegarty, 2012; Mestre & Vercher, 2011). For example, a study conducted by Bioulac et al., (2012) found that VR technology was a good clinical tool to evaluate ADHD children attention. Likewise, Attree, Turner, and Cowell's study (2009) found that diagnosing dyslexic children's VS potential based on VR approach was more accurate compared with paper-based approach. However, their study focused only on the way finding aspect of VS skill, which used a standalone VR application.

As of today, there is no universal definitions and classifications of VR technologies. Nonetheless, to explain various VR technologies and to facilitate the development of VR applications, several researchers have proposed three types of VR based on the level of immersion: fully-immersive, semi-immersive and non-immersive (Bamodu & Ye, 2013; Halarnkar, Shah, Shah, Shah, & Shah, 2012; Ramaprabha & Sathik, 2012). Using this classification, discussion on VR applications can be made more specific by referring to a particular type of VR.

Among the three types of VR, non-immersive VR is an affordable, easy-to-implement VR technology reaching a wide range of users – teachers, students, or instructors. Non-immersive VR can be readily developed and implemented using a standard desktop computer compared to fully- and semi-immersive VR that require special equipment, such as special gloves, head-mounted display, or a stereoscopic screen. Furthermore, several studies have found that fully- and semi-immersive VR applications could induce users with cyber sickness such as nausea, or disorientations (Ausburn, Martens, Washington, Steele, & Washburn, 2009; So et al., 2011). On the contrary, a study conducted by Polcar and Horejsi (2015), found that non-immersive VR users did not experience cyber sickness or disorientations when they explored a virtual world. In fact, non-immersive VR has been found to be as equally efficient as the semi-immersive VR in helping users to gain spatial knowledge.

According to some researchers (Fuchs & Guitton, 2011; Gabbard, 1997; Kalawsky, 1999; Ramaprabha & Sathik, 2012; Sherman & Craig, 2003; Sutcliffe, 2012),there are two main elements that distinguish VR applications from 2D- and 3D-multimedia applications, namely immersion and interactivity. Essentially, immersion is a unique feature that only exists in VR applications, thus both of these elements should be taken into account when designing a VR application or a tool.

Likewise, interactivity is also a unique element of VR applications involving spatial and temporal dimensions that are lacking in 2D- or 3D-multimedia applications. More importantly, Ramaprabha and Sathik (2012) assert that users would not be able to experience immersion in the virtual environment if interactivity is not accorded to them. Furthermore, Fuchs and Guitton (2011) emphasize that interactivity is an important element in VR that has to happen in real-time, where there is no delay between user's actions in virtual world and system response. In this respect, withal Sherman and Craig (2003) highlight three types of interaction involved to help users communicate with VR applications, namely manipulation, navigation, and communication. To deal with these interaction types, several researchers have developed design guidelines for VR applications (Gabbard, 1997; Sutcliffe, 2012).

Based on the discussion in the preceding section, the researchers propose a new, novel testing tool called "Web Based Non-Immersive Virtual Environment Application" (WEB-NIVEA) to help diagnose the VS potential of special children such as dyslexic children with greater robustness and improved precision. More specifically, this paper elaborates on the design of appropriate virtual environments involving two vital designing phases, namely Task Analysis and Domain Models, which were adapted from Sutcliffe's VR methodology (Sutcliffe, 2012).

## 2.0 METHODOLOGY

The development of VR applications is more complex than 2D- and 3D- multimedia applications as the former has unique characteristics, such as realism, latency, physical factors, etc., thus requiring greater detailed design considerations. To cater this need, several methodologies for VR development have been proposed by several scholars as follows: i)Structured Approach (Jounghyun, 2005), ii) Instrumental Approach (Fuchs, Lourdeaux, & Burkhardt, 2011), and iii) VR development approach (Sutcliffe, 2012). The researchers adapted the third methodology for the development of WEB-NIVEA because this methodology provides a distinct function for every phase of the development to create a functional virtual environment. Moreover, this methodology also provides a guideline for a goal-directed exploration approach.

The methodology of VR development proposed by Sutcliffe has five phases: a) requirement analysis, b) task and domain analysis, c) design of a virtual environment, d) development of a prototype, and e) evaluation. However, this methodology lacks emphasis on optimization techniques during the development process. Optimization techniques must be applied during the development process of web-based applications so that the applications would strike a good balance between speed (of deployment) and realism, with the former dictated by the file size. Essentially, the application's file size needs to be made as small as possible, lest it could result in slow downloading of contents, ultimately leading to poor latency. Thus, some adaptations had to be performed on this methodology. The first adaptation involved dividing the second phase into two distinct phases, namely task analysis and domain model. This division was vital because the domain model phase had to be repeated several times without involving the task analysis phase. During designing the virtual environment of WEB-NIVEA, some changes had to be made to the objects or terrains in order to reduce the file size to further improve its performance. Essentially, a terrain consists of meshes with a variety of surface textures that makes up the ground of a virtual outdoor scene such that it would appear as a real outdoor scene consisting of mountains, deserts, and islands (de Byl, 2012). To deal with this need, these changes were carried out in the domain models only, and not in the task analysis phase. In addition, several optimization techniques were applied in the designing of WEB-NIVEA to avoid unnecessary fine details that would increase the file size. In addition, a formative evaluation was carried out in every phase of the development process of WEB-NIVEA. Figure 1 summarizes the adaptation of Sutcliffe's (2012) VR methodology.

### 2.1 Task Analysis

The Task analysis phase is the stage at which an analysis of the functions or services provided by a VR application is carried out. This phase consists of three sub activities as follows: i) the function of the application, ii) the interaction properties (e.g., manipulation complexity, haptic feedback, perceptual feedback, cognitive feedback, limbs and body parts, and navigational requirements), and iii)the activities of application (Sutcliffe, 2012). While carrying out the activities in this phase, the task analysis should also take user's prior knowledge, experience, and skills into consideration.

#### *2.1.1 Functions or Services Provided by the Application*

In this study, the function of WEB-NIVEA was to create a VR environment in which dyslexic children (as users) could explore to solve a series of tasks. Each task would entail the user to take a test to help diagnose

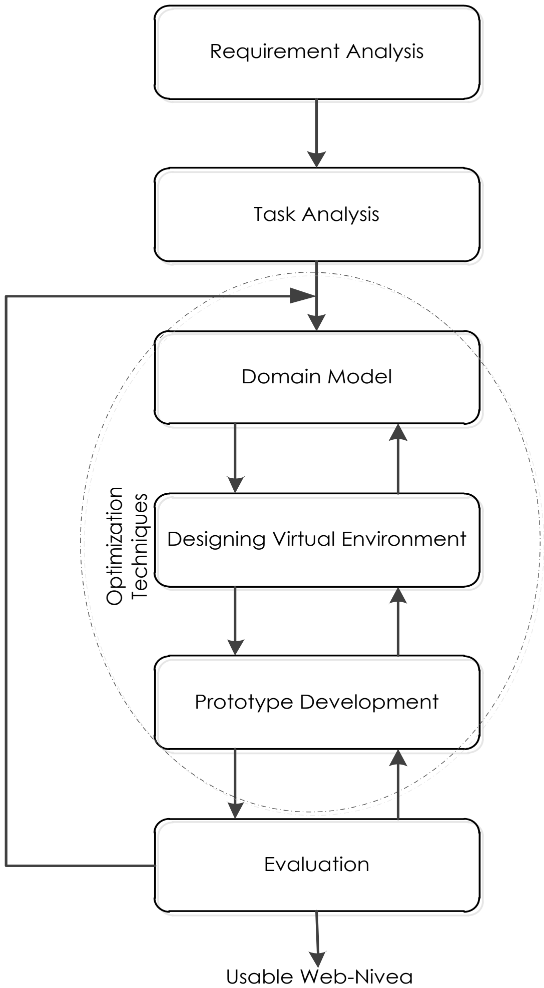



**Figure 1** WEB-NIVEA Development Methodology (adapted from Sutcliffe's VR Methodology)

his or her potential. Essentially, the VR environment was created as a mini game in which the user is required to seek a hidden treasure. In seeking this treasure, the user would navigate the scene, and at a certain spot the user is required to solve a task. Altogether, there is a series of tasks consisting of three levels of difficulty, with each task having 10 questions. In this VR environment, the user has to solve a low-level task before proceeding to a higher-level task. The purpose of the three-level game tasks, progressing from simple to complex one, is to motivate the user to explore the VR environment in which he or she would be tested accordingly. Having this motivational element in the VR environment is important to engage users, especially dyslexic children, so that learning or training would become efficacious, not spurious (Nor Hasbiah, 2007).

To ensure sustainable engagement in the VR environment, the design of VR diagnostic tool was based on the principle of goal-directed exploration (Sutcliffe, 2012) by which the user would navigate and explore the environment to attain certain target goals. To achieve the intended goals, this approach would be able to motivate children to take a series of test as part of a game in a VR environment. This virtual environment was designed and developed as an outdoor environment as suggested by the respondents in the analysis phase.

In view of dyslexic children's problem in reading (Baillieux et al., 2009; Davis & Braun, 2010; Eide & Eide, 2011; Subramaniam, 2008), the VR game was built with a display of navigation tools and complemented with audio instructions to enhance usability – the latter would help users to better understand the instructions. Furthermore, a tutorial would be provided to the children to help them familiarize with the two types of figures before they taking such tests.

To improve interaction, WEB-NIVEA would also display keys to facilitate the user to interact with the application. To prompt the user to solve a particular task, an image (i.e., a "flagpole" icon) would also be placed at a strategic location. According to the goal directed exploration guideline (Sutcliffe, 2012), the user should be able see a target easily and clearly, thus compelling the researchers to place a flagpole at each spot. Figure 2 depicts the "flagpole" image to alert the user to a task, which needs to be solved.

**Figure 2** A flagpole at the answering station

Coquillart, Fuchs, Grosjean, and Hachet (2011) assert that virtual environments should be created in such a manner to help users navigate easily to perform their task. Thus, based on this suggestion, the researchers placed important cues such as arrows and a mini map to show the current position of a player in the environment. Using these cues, users would be guided to navigate the environment without the risk of getting lost or disoriented.

More importantly, WEB-NIVEA would provide the most needed function that could help test dyslexic children to diagnose their VS potential. The VS potential is divided into five categories, namely *Extremely high, High, Moderate, Average*, and *Low*, depending on the test scores obtained. Table 1 summarizes the levels of VS potential based on the range of scores.

**Table 1** Levels of VS potential and range of test scores

| No. | *Level of Potential* | *Range* |
|---|---|---|
| **1** | Extremely high | 95 - 100 |
| **2** | High | 80 - 94 |
| **3** | Moderate | 60 - 79 |
| **4** | Average | 40 - 59 |
| **5** | Low | 0 - 39 |

The potential level would be displayed accordingly with the level of the game. For example, if the user performed poorly in the first-level task, his or her VS potential level would be displayed to inform the user of his or her VS skill or ability.

### 2.1.2 WEB-NIVEA's Interaction Properties

In WEB-NIVEA, there are three forms of interaction properties, namely perceptual feedback, navigation, and cognitive feedback, to assist the user to solve the tasks. For perceptual feedback, WEB-NIVEA would deploy a monoscopic screen to simulate the VR environments. To create a sense of high realism, music and sound were embedded together with visual presentations.

For navigation and exploration in the virtual world, the user would use arrow keys, a mouse, and a space bar to move in the environment. These keys were chosen by taking into account the difficulty of dyslexic children in recognizing certain alphabets, especially the lowercase letters *b, d, w,* and *m* (Davis & Braun, 2010; Eide & Eide, 2011; Subramaniam, Mallan, & Mat, 2013). Thus, it is imperative to avoid using these letters in the virtual environment. Furthermore, based on a study by Lapointe, Savard, and Vinson, (2011) these devices (i.e., arrow keys and a mouse,) are deemed appropriate to help navigate in the virtual world.

For the cognitive feedback, the user must first view the object and then determine the type of object in a given time by pressing "Y" or "T". On approaching a station (i.e., a flagpole), audio instruction (in the form of an audio file) would be triggered to prompt the user to answer a question.

All the interactions in WEB-NIVEA would involve minimal sensory motor coordination – without haptic devices or special equipment, such as gloves or head mounted display. WEB-NIVEA would only employ minimal interaction to help the user to interact with ease by using familiar hardware interfaces. Using expensive, complex hardware interfaces is not only cumbersome but also slow, as haptic interfaces or special equipment need to update the display and feedback continuously when the user moves objects or bodies at certain angles or positions in the virtual environments. According to Coquillart, Fuchs, Grosjean, and Hachet, (2011), this updating is a challenging process because simulating actual physical movements in the virtual world could be complex due to several factors, such as gravity, speed, movement, area, and techniques used.

### 2.1.3 WEB-NIVEA's Activities

WEB-NIVEA's activities could be divided into two main categories, namely goal directed exploration and solving impossible figure tasks. For the first activity, there is no time limit to explore the 3D environments, as it would not affect the result. Enforcing time limitation is not suitable for this activity as the children might be unfamiliar with the 3D scenes. Thus, no time constraint is enforced to enable the user to explore the environment. Furthermore, as suggested by Sutcliffe (2012,), to avoid the user getting lost in the virtual world, the exploration paths were created for each environment. Figure 3 shows a bird's-eye view of the exploration path in WEB-NIVEA.

**Figure 3** A bird view of the exploration path.

For the second activity, impossible figure tasks would be used as the test instrument as previous research has shown that these tasks are suitable to diagnose dyslexic children's potential (Chan, 2009; Von Karolyi, 2001; West, 2003). Solving these tasks entails the user to determine whether the objects or figures in a scene could truly exist in the real world or not. Alexeev (2013) defines an impossible figure as a 2D image that could not exist in a 3D world. Moreover, according to Browne (2007), impossible objects are the result of an optical illusion in visual perception which creates misleading figures with ambiguous, contradictory perceptual interpretations. If each geometrical part of the object is viewed locally, it would appear as a logical object. However, if the geometry of the object is viewed globally, then it would look like as an impossible object.

The researchers referred to impossible figure website library (http://im-possible.info/english/library/

index. html) to model these objects. Figure 4 depicts an example of the impossible figures.

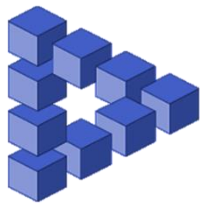


**Figure 4** An example of impossible figure

When the application prompts the user for a response, the user needs to press "Y" for a possible figure or "T" for an impossible figure. The letters "Y" and "T" stand for "Ya" (meaning "Yes") and "Tidak" (meaning "No"), respectively. The user would be given only one attempt to answer each question. If the user skips this question, he or she would not be given another attempt to deal with it later.

Altogether, there are 30 figures consisting of 15 impossible figures and 15 possible figures. Table 2 summarizes the breakdown of the number and type of figures used in the application A time limit needs to be imposed because prolonged viewing could reveal the exact nature of the figures. Thus, every object would only be displayed for 10 seconds. There is no specific time limitation for such display of objects as it depends on specific context of a particular task. For example, in Von Karolyi's study (2001), the time allocated for a user to see an object and to provide an answer was 25 milliseconds. In contrast, in Chan's (2009) study, the time allocated was one second. In this study, the researchers propose 10-second time limit to solve the tasks. However, this duration may change after performing beta testing. Figure 5 depicts the overall activities of the task model.

**Table** 2 The number and type of figures.

| Level | Total number of Impossible figures | Total number of possible figures |
|---|---|---|
| **1** | 5 | 5 |
| **2** | 4 | 6 |
| **3** | 6 | 4 |
| **Overall** | 15 | 15 |

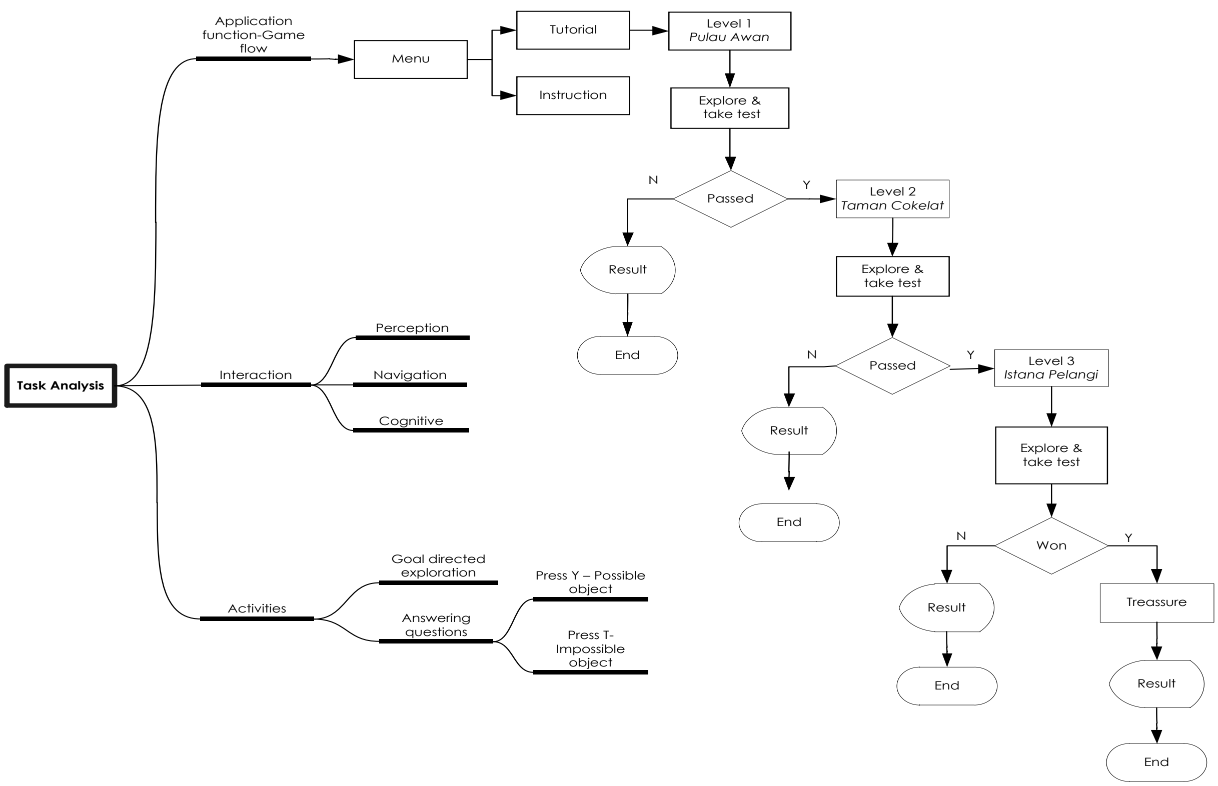



**Figure 5** Overall activities of task analysis

## 2.2 Domain Models

Domains are the part of the world that needs to be presented in the virtual environment, entailing the transformation of actual, real attributes of the real world into the virtual world with appropriate virtual agents (Sutcliffe, 2012). To create such an environment, the domain model must address all the elements of the VR application such that the synthetic (virtual) environment created could mimic the actual, real environment. In addition, other vital elements (e.g., music, color, sound, lighting, and texture) must also be carefully discerned and chosen to enhance the synthetic environment to make it look appealingly real. Furthermore, active virtual objects would be added to the synthetic environment to enable the user to interact in a natural way. In WEB-NIVEA, the domain model consists of appropriate environmental themes.

For WEB-NIVEA, three types of virtual environments were developed and deployed, namely *Pulau Awan*, *Taman Cokelat* and *Istana Pelangi*. These environments are deemed appropriate for dyslexic children who have unique abilities, such as creative and imaginative thinking, as found in previous studies (Davis & Braun, 2010; Eide & Eide, 2011; Marazzi, 2011; West, 2003). Hence, the above environments were developed to include relevant attributes to engage children in the learning process, to foster their creativity, and to heighten their motivation.

The active objects for the first environment are clouds that hover above the virtual island, grass foliage, and shrubs that would be suitable for the chosen theme. To add a sense of realism, there is a stump door that would open and close every time the user enters and leaves an "answering" station, respectively. Each object was placed inside the stump as depicted in Figure 6b. Thus, when the stump door opens, the user could see the object or figure when answering a question.

(a) (b)

**Figure 6** Active stump door: (a) closed stump door, b) opened stump door with an object

On the other hand, the inactive objects modeled in this environment are the flagpole, impossible and possible figures, pebbles, and bedrocks.

As for the second environment *Taman Cokelat*, the active object is the *Lollipop door* that was placed at the object of the task. This door would react as the same way as the stump door. The inactive objects in this environment consist of candies (of various shapes), chocolates, lollypops, flagpoles, and task objects (i.e., impossible and possible figures). To elicit a cheerful ambience, all the candies and chocolates were modeled with striking colors.

Lastly, for the third environment *Istana Pelangi,* the inactive objects consist of a palace, a rainbow, huts, and trees. Likewise, the impossible and possible figures are also treated as inactive objects in this environment. The active objects of *Istana Pelangi* include the hut door and castle door. The function of the hut door is similar with the function of the stump door, which is to place the task objects; whereas, the castle door would open after the player has performed all the tasks successfully. The environment created contains a beautiful scenery to attract the attention of the children, which could lead to persistent exploration and undertaking of diagnostic tasks.

Lighting elements play an important role to harmonize all the virtual objects in the environment. These elements engender realistic environments to engage the user more actively. However, the developer needs to use them judiciously, lest the performance of an application, especially if it runs on the web, would be compromised. This performance degradation is due to the rendering process of lighting elements, which incurs a high computing overhead. Thus, to reduce the load of rendering process, all the three environment would simulate daytime scenes, which require few lighting elements, instead of night scenes, which needs many lighting lights. To circumvent the problem of creating realistic scenes without too much processing demand, the researchers propose the use of different types of backgrounds for the three environments.

Another optimization approach that was applied in this phase was to use fewer polygonal objects. Although, a higher polygon count results in a more realistic object, but the rendering of the virtual object would be laboriously slow. This slowness is due to a high number of polygons that needs to be processed (de Byl, 2012), resulting in sluggish games or applications. This problem would be made worse if the applications run on low-end computers, which typically lack the processing power. In view of this problem, the researchers carefully selected appropriate objects that could be modeled optimally using fewer polygons.

Lastly, for the agent of WEB-NIVEA, the researchers propose a first-person controller in exocentric view or first person perspective. This perspective allows the user to see the impossible figures without any distortions when he or she navigates the scene. Furthermore, in this perspective the agent would act as an outside person where the image on the screen represents the user's view looking from the outside as shown in Figure 7.


**Figure 7** First person controller in exocentric view

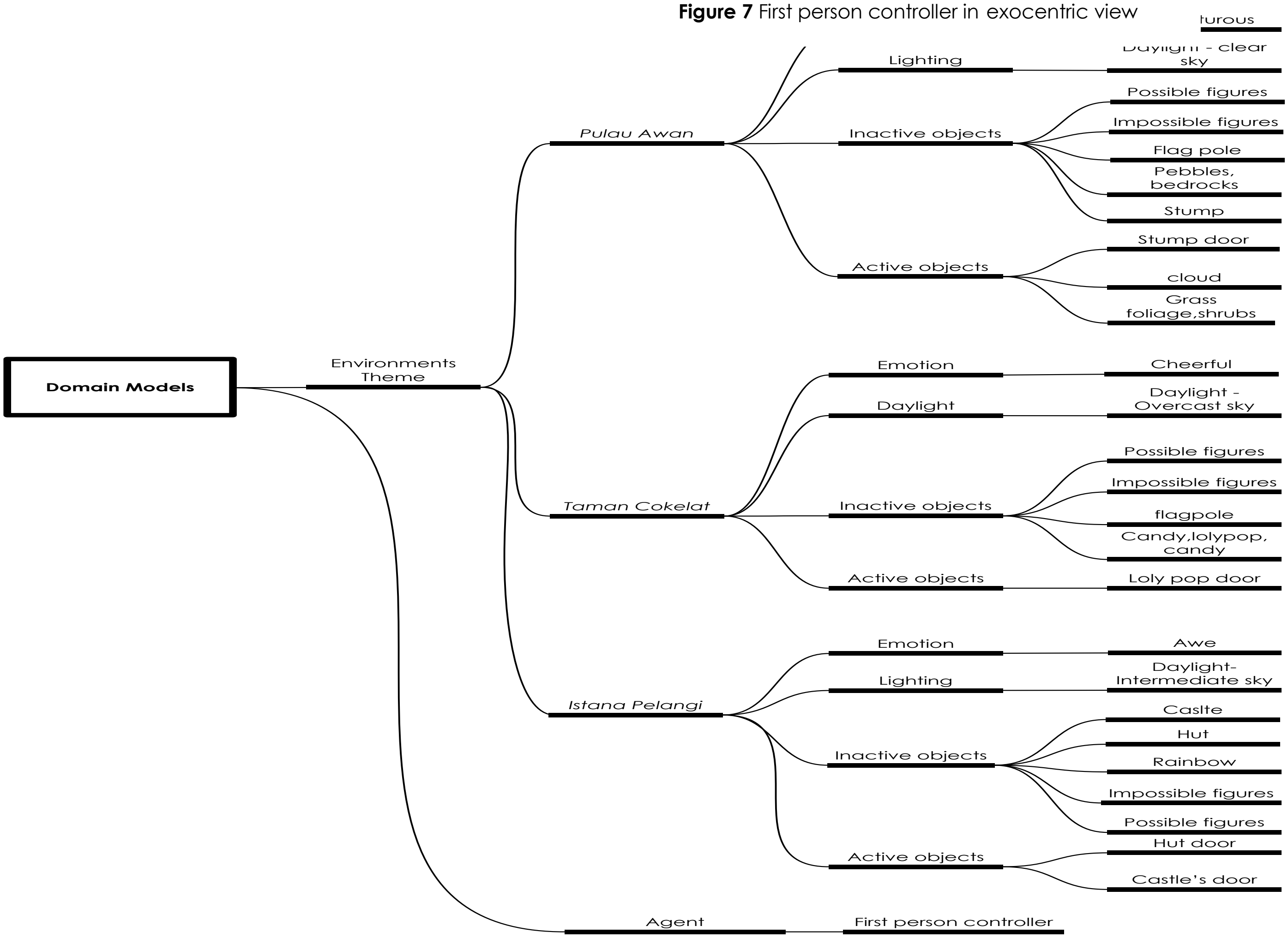



**Figure 8** Overall description of domain models

## 3.0 CONCLUSION

Using non-immersive VR technology requires a new design methodology to help developers build effective learning or training solutions. In this paper, the researchers discuss the use of a methodology based on Sutcliffe's VR methodology (2012) and goal directed exploration approach principle in the design and development of such a tool called WEB-NIVEA, which is intended to be used as a diagnostic tool for dyslexic children. This design methodology imposes two main phases, namely tasks analysis and domain models to create compelling, efficacious testing tools. In discussing these development stages, the researchers highlight relevant VR features and characteristics of dyslexic children. For the former, the elements of realism and interaction of the non-immersive VR were examined and used in the design of WEB-NIVEA. For the latter, unique characteristics of dyslexic children such as their innate VS skill were examined. Combining the former and the latter enabled the researchers to create appropriate virtual environments that are both educational and entertaining. Given that WEB-NIVEA is a web-based tool, its performance depends on the speed of deployment over the web, thus several optimization techniques were used to optimize the application's file size. Overall, this study demonstrates that using appropriate development methodology and optimization techniques would help in developing an affordable, effective testing tool.

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