POSEiDON

PersOnalized Smart Environments to increase Inclusion of people with DOwn's syNdrome

Deliverable D4.4

Virtual Reality System

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Table of content

1. Executive summary

The deliverable D4.4 - Virtual Reality System v1 is the fourth deliverable of Work Package 4 - User Interaction and it is associated to Task 4.1 - Interface language. This deliverable is closely connected to D2.1 - Report on requirements and D2.3 - Report on Design of Hardware, Interfaces, and Software, using the collected requirements in the development of a common user interface for all the interaction paradigms that will be designed in the scope of WP4.

The aim of this deliverable is to present investigations on the use of Virtual Reality (VR) in developing a system meant to train independent living abilities for people with Down Syndrome (DS), in the context of the POSEIDON project. After reviewing the existing research on the rehabilitative potential of the VR/Augmented Reality (AR)/Mixed Reality (MR), we propose a strategy that covers several aspects such as hardware and software requirements and provides an analytical description of the training tasks that will be simulated and practiced in the Virtual Environment (VE). A first prototype was presented through a series of tests to the stakeholders in order to evaluate the system and to obtain their feedback. This led to a new approach in which we produced a solution that was less virtual and kept more elements from the real world. Our analysis considers also possible implications or integration issues that might arise during the project. In the end, we investigate the effectiveness of the virtual support and training system. In this document, we present the various iterations that we continuously been done while building the presented system. Our spiral methodology consisted of different phases where we interacted with the stakeholders in order to co-design a system with training potential for the primary users.

2. Introduction

In the UK, the overall diagnostics of people with Down syndrome (DS) has risen by 71% over the past 20 years (from 1075 cases in 1989 to 1843 cases in 2008). People with DS are usually socially excluded; very few have jobs or live in their own homes. The general expectation is that they need to achieve independence and to be included in the society. Thus, they need to have as much choice and control over their lives as possible, be involved in their communities and make a valuable contribution to the world or at work.

People with Down syndrome (DS) (and more specifically children) exhibit several common characteristics: delays in motor milestone attainment, sensorimotor performance deficit, and perceptual dysfunctions, in addition to significant limitations both in intellectual functioning and in adaptive behaviour. They are characterised by perceptual-motor slowness, limb control problems and decreased motor proficiency, and are in general slower at executing goal-directed movements compared to typically developing peers. Children with DS present a series of challenges for carers and teachers, as they require carefully considered instructions that guarantee the quality of the physical education process (Pitetti *et al.*, 2013). All of above-mentioned implications greatly affect the independence of people with DS in everyday situations, thus compromising their social acceptance by other people. It is therefore of paramount importance to create a system that will assist them in everyday tasks, helping them to become more independent.

Literature has already shown that VR can make a significant difference for people with cognitive disabilities. As we show in the following subsections, the problems that have been improved as a result of VR rehabilitation sessions cover many areas. After presenting the advantages of VEs and its use in learning and rehabilitation applications dedicated to people with different disabilities, we offer an overview of our proposed system.

2.1 Advantages and uses of VR systems in disability rehabilitation

So far traditional therapies used to deal with motor and cognitive disabilities have had limited success(Jeffs, 2010). Reasons for this could be: 1) the very nature of children with DS disabilities (i.e. movement limitation, attention deficit, or cognitive impairments) that makes them unable to repeat a functional activity, or 2) the lack of intervention context variability, that does not allow them to adapt to different training conditions. These reasons turned the scientific interest towards using VR systems to create exercise environments in which auditory and visual feedbacks could be systematically manipulated in order to allow for individualized training.

Indeed, during the past few years, there has been an increased interest regarding the use of VR environments for the creation of systems that act as assistive aids for people with cognitive disabilities, such as autism, DS etc. Within this context, because of the advantages VR systems provide (e.g., safe training environments, observed reduced training time), they started to be often used in cognitive disabilities rehabilitation. They provide solutions by creating teaching/learning tools, in which people with cognitive disabilities can easily interact with real life objects while trying to accomplish the task that was assigned to them or practicing skills that could have been otherwise risky in real life conditions.

Acquiring and maintaining skills through practice is many times difficult for people with cognitive disabilities in real world situations, as they are often denied such experiences. However in a VR environment, things become easier, as it encourages interactive learning and provides a variety of opportunities that allow the user to actively participate in the learning process. Moreover, VR tools are safe and supportive and as it is stated in the literature, a variety of domains in which the knowledge acquired in the virtual setup has been successfully transferred to the real world are available.

In this subsection, we will present an overview of the relevant research that evaluated the use of VR environments for individuals with special needs. We will focus on investigating the effectiveness of the proposed VR systems for a variety of problems that are also characteristic to people with DS: 1) physical disabilities, 2) sensory impairments, 3) mild to moderate cognitive disabilities, and 4) learning disabilities. We will discuss highlights for each specific problem.

2.1.1 Physical disabilities

Children with DS have a variety of physical problems and difficulties that can affect their motor development. Such children present a series of challenges for carers and teachers, as they require carefully considered instructions that can guarantee the quality of the physical education process. Their motor skills are reported to be below their aged-matched peers, as they are affected by a series of deficits in aspects like timing, maintaining balance, co-ordination, muscle tone and strength.

Balance is one of the most affected ability for people with DS, they usually are not able to maintain their equilibrium on one foot or with closed eyes (Carmeli et al. 2002). Despite the fact that there is no cure for this disorder, there is evidence that their delayed development can be reduced with rehabilitation intervention.

VR based therapy has a great potential in the rehabilitation technology, allowing users to interact with virtual objects and perform actions that immerse them in the virtual environment. Literature presents evidence of the efficiency of VR based therapy when using Nintendo Wii. This system consists of a console that attaches to a standard television, a wireless handheld controller and several additional peripherals. One peripheral of particular interest is the balance board that contains several sensors to measure body weight. Although originally designed for entertainment, it started to be used more and more in a practice called Wii-habilitation.

In (Abdel & Abdel 2010) the authors present a study that examines the effect of Wii Fit on balance in children with DS. The results were encouraging because they revealed a significant improvement of balance in the study group that consisted of 30 children with DS. These results were in concordance with other similar findings for people with DS presented in (Berg et al. 2012). The effectiveness of Wii Fit games in improving balance between two individuals with a lower limb amputation was studied in (Miller et al. 2012). After 6 weeks of practice, both participants demonstrated improvement in dynamic balance and balance confidence.

Since its release in 2006, Nintendo Wii has been often used in conjunction with video games and it's considered a potential adjunctive tool for physical rehabilitation (Goble et al. 2014). Despite this, further research is needed to completely understand its utility range and also the various roles that VR can play in the rehabilitation process.

2.1.2 Sensory impairments

Individuals with sensory impairments face many challenges in one or more of the three senses – vision, touch or hearing. Technology cannot remove these impairments, but it has the potential to train a person to acquire functional and cognitive skills. VR provides the possibility to manipulate visual and auditory inputs and outputs. Thus, learning can be customised to promote different activities. Usually these systems consist of haptic devices for input and auditory information as output channels.

2.1.3 Mild to moderate cognitive disabilities

For people with cognitive disabilities, it is usually hard to gain new skills because of the intellectual processes and their limited access to learning. Intellectual processes are related to tasks like reasoning, planning, sequencing, remembering, processing and cognitive speed. Their limited access to learning means that often they cannot engage in learning materials in the appropriate format.

VR environments have been often used to teach community literacy and daily living skills such as: community literacy skills (reading or discriminating printed brand names), mobility skills (navigation within a store), purchasing skills (buying groceries), social skills (asking for assistance), safety skills (reading signs that decrease danger) etc. (Langone et al. 2003).

In (Standen et al. 2006) VR learning environments have been closely examined with an emphasis on the advantages they bring for people with moderate disabilities. These advantages are related to the opportunity of repetition and control over the learning process.

2.1.4 Learning disabilities

Until the recent years, VR for people with learning disabilities was focused on life, social and vocational skills (Cobb & Sharkey 2006). Nowadays the attention is shifted on helping people with cognitive disabilities to obtain also academic skills. For example, there are many VR applications that children with learning disabilities could benefit from using:

- Newton World (http://www.virtual.gmu.edu/ss_worlds/newton.htm),
- Maxwell World (http://www.virtual.gmu.edu/ss_worlds/maxwell.htm)
- Pauling World (http://www.virtual.gmu.edu/ss_worlds/pauling.htm)
- Zoninginon Physics (http://cehd.gmu.edu/assets/ziop/index.html).

These VR environments allow the users not only to view events, but also to experience them. This could be effective in the understanding of abstract concepts like: Newton's laws of motion or solar system. Thus, VR became a promising avenue that allows people with cognitive disabilities to gain problem-solving skills.

Based on these results, we strongly believe that applying virtual elements to the learning process could have a positive impact on the learning outcomes leading to an increased independence in the everyday life of people with DS.

2.2 Virtual and Augmented Reality system in POSEIDON

POSEIDON aims at creating a system that will be used as an educational tool for people with DS, enabling them to effectively train in several essential everyday tasks, in order to promote their independence while simultaneously ensuring their safety. Considering the potential of VR that has been showed in numerous studies presented in Section 2.1, our first approach was to build a virtual environment that could be used for understanding and rehearsing successions of steps related to different tasks (e.g., travelling, finding your way through a building, preparing tea).

This VR system, in its typical form, includes several carefully designed tasks, that will train the individual to deal with everyday typical situations, for example using transportation means, planning a route, dealing with heavy traffic in crossing lights, preparing breakfast, etc. Our aim is to increase the independence of people with DS while dealing with their everyday limitations. Our focus is oriented on navigation skills, but the implementation considers also the development of social, safety or literacy skills.

The proposed VR system was interconnected with a mobile phone (described in D4.2), and an interactive table (described in D4.3), aiming to provide support for planning tasks or for context-based learning. It is clear here, that in order to achieve that, the VR system had to be available on all platforms developed and used within POSEIDON. More precisely, a consistent version, in terms of the basic functionalities and interface features, had to be developed. The offered support consisted of: a VR application for home use, meant to train users to navigate in a given environment, and a mobile phone application meant to support the individual outside by adding to a map, based on GPS location, extra information at home or on the way to a destination. The system (see abstract representation in Figure 1) consisted of:

a) A full version that includes high quality graphics, an immersive virtual environment and all advanced options. The application ran from a standard desktop system located at the house of the person with DS. We envisaged this version as able to communicate with the interactive table, in order to promote alternative ways of interaction with the user, besides the typical mouse and keyboard. The home VE was meant to be used by the person with DS (for training purposes: e.g., how use a printer), but it was also accessible to the carers, who were able to upload audio-visual material (for example images or videos, see Section 3.2.3) in order to customise it to the user's needs.

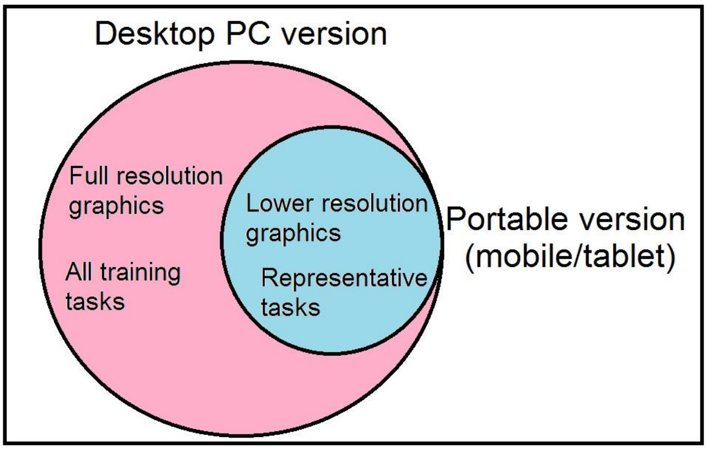

Figure 1. VR system (full and light versions)

b) A light version that can be used on the portable platforms, such as the user's tablet/mobile phone. This version included only the basic functionalities that allowed the user to undertake a task effectively, without being confused by the fact that he/she deals with a portable device. Therefore, it was of extreme importance that the interface features of this version, as well as of the full version described in a) remain the same, thus avoiding confusion. Moreover, the only objects present in a scene should be those necessary for the execution of a specific task. The carers should not be able to interfere with the light version, but should be able to know the physical position of the person with DS at any time, in case help is required.

We should however emphasize here, that in order for such a VR system to succeed in being an assistive tool there is a need for interaction and collaboration between the members of the technical and clinical communities. Detailed feedback from the methodology we applied in the interaction of real users (people with DS) with the proposed system is presented in Section 5. This was achieved through planning several testing procedures that enabled POSEIDON to acquire the desired outcomes (see Section 5.2).

2.3 Paper organisation

This document presents first the perspectives of VR for rehabilitation, especially for the acquisition and maintenance of skills necessary for independent living in case of people with cognitive disabilities. The first part includes also a review of existing research on the rehabilitative potential of VR. Subsequently, we will present our initial project strategy, covering several aspects, like hardware and software requirements, as well as providing an analytical description of the training tasks that will chose for the VE training. Moreover, we discuss the implications that arose due to software and integration issues and we present how our solution evolved from a fully virtual representation to a one that is more realistic but enhanced with information customized for each user.

3. Initial strategy

In this section we will first generally describe the relationship of the developed VR system (with goals and subgoals described in Table 1) to the specific requirements set in deliverable D2.1 - Report on requirements. We will proceed with presenting the requirements in two categories, those that deal with hardware issues and those that focus on the functionalities the system should have. Subsequently, we will present the VR system in detail.

Virtual Reality system goal	Subgoal
Suitability for persons with DS	• Support outdoor social activities • Support travelling • Support training tasks • Provide extra guidance with regards to familiar locations
Suitability for family	• Design task efficient aspects
Suitability for carers	• Task efficiency should be ensured
Support for adaptive user interfaces	• Support various client devices • Cost less than 600 euros • Offer options for interaction
Conformance to standards of the different technical systems	• Possess graphical capabilities for rich environments • Use a common API with interactive features • Offer options for interaction

Table 1. Goals and subgoals of the VR system

3.1 Key hardware requirements of the VR system

In this subsection we will describe the requirements that deal with hardware issues, as specified in deliverable D 2.1 - Report on requirements.

3.1.1 Portability-support various devices

The developed VR system provided support for all platforms considered within the POSEIDON framework. It was, therefore, fully functioning in a standard desktop system located at the house of the person with DS, as well as in his/her tablet/mobile phone. The different versions developed for this purpose did not differ in a great extent, so that they do not cause confusion to the users.

3.1.2 Posses sufficient graphical capabilities for rich environments

The developed VR system possessed sufficient graphical capabilities in order to support rich environments. The VR system version that was used by the standard desktop PC located at the users house contained the full resolution graphics, to create a convincing VE in which the users will immerse more effectively. The portable versions was used for the tablet/mobile phones will be lighter, and therefore used graphics of lower resolution, in order to promote transferability and user independence while on the go. The core things displayed to the user were as similar as possible, in order to ensure that the person with DS is not confused by the different platforms.

3.1.3 Offer interaction options

This requirement is mainly focused on the version of the system developed for use on a standard desktop PC located at the house of the person with DS. In that case, alternative interaction options were offered. The user was be able to choose whether to interact with the VR system using typical means that he/she is accustomed to (e.g. keyboard or mouse) or using more sophisticated options, like the interactive table (described in D4.2 v.1). The user is the one who decides how he/she wishes to control the system, according to his/her personal abilities and preferences.

3.1.4 Use a common API with table

Directly linked to the requirements described above, we used a common API to link our training solution with the interactive table. The common API allowed for easy, quick and effective collaboration of the two systems (table and VR) while preventing any problems that may be attributed to hardware incompatibilities. Thus, future additions or adjustments were easier, as the common API eliminated the possibility of errors.

3.1.5 Be reactive with real-time rendering

Our training system offered real-time interaction with the user. This was present in all its versions (full one developed for the standard desktop PC and light one developed for the tablet/mobile phone). The results of the user's interaction with the system should be updated real-time, so that the user is not confused.

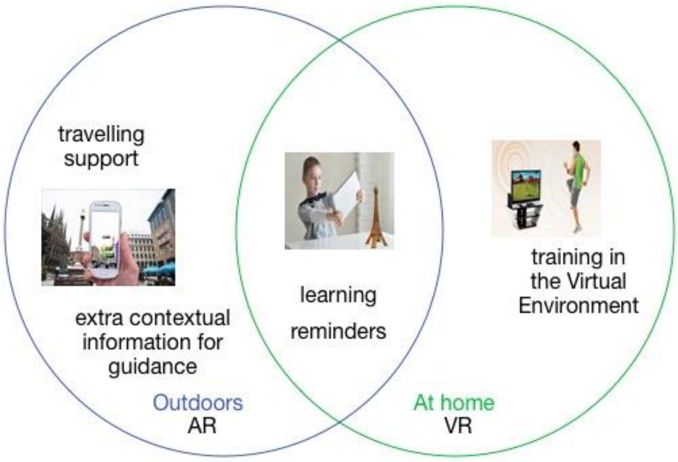

Figure 2. A general representation of our initial strategy

3.2 Key functionalities of the VR system

In this subsection we will describe the functionalities the VR (see Figure 2) system should provide to the user, as specified in deliverable D 2.1 - Report on requirements.

3.2.1 Support outdoor social activities

Social interaction with other people plays an important role in the lives of people with DS. Therefore, it is of outmost importance for the VR system to provide a functionality that will help them to arrange gatherings with friends, communicate with each other and in general keep in contact with other people. Whether this should appear in the format of emails, or of a more sophisticated system (messenger or social networks), it is an option that will be offered by the system but will be customisable according to the user's abilities and preferences.

3.2.2 Support travelling

To master travelling on their own is an important competence to foster independence for people with DS. Experiences show that once learned, many people with DS are perfectly able to travel on their own. However, learning new routes and handling exception situations can represent huge challenges. This involves travelling to school, to work, or even to a meeting with friends. Therefore providing a secure and effective way to provide guidance, in order to allow them to travel independently is one of the VR system's top priorities. The developed VR system will provide several means of travelling, either by using public means of transportation (bus, train) or on foot.

3.2.3 Provide extra guidance with regards to family location

The developed VR system will allow carers to interfere with the guidance procedure when planning a route, by uploading material that will make the navigation for users (people with DS) easier. For example, the carer will be able to add images, videos, narrations of previously visited places, so that the user can identify those places in an easier and more effective way. By adding that functionality, we wish to minimise the chances of confusion for the users that may potentially lead to panic attacks, when something does not go as planned.

3.2.4 Support training tasks

The prime role of the VR system will be to educate/train the users (people with DS) to specific tasks, in order to help them be more independent in their everyday lives. To achieve that, specially chosen tasks have to be offered, that will be general enough to allow for training under different circumstances (for example, different kinds of buses in each country). It is infeasible and impractical to create a virtual environment for every possible place each user can visit. We therefore focus on providing a general training that will help people with DS deal with certain common situations, such as how to get ready for school, how to use public means of transportation and how to create a route using the application provided from POSEIDON. More details regarding the tasks that are included in the first version of the VR system can be found in Section 3.5.

3.2.5 Be a customisable VR system

The main characteristic of the VR system is that it will be customisable to its user's needs. A basic level of functionalities will be available for each user, which can be drastically altered to reflect the user's abilities and preferences. For example, if the child with DS has good motor skills, his/her interaction with the VR system will be performed using the Kinect system or the interactive table. Another example can be that of a child with DS who is more independent and therefore requires more advanced training skills (for example how to arrange a meeting with friends in a crowded place).

3.3 Devices to use

As mentioned earlier, children with DS are characterised by perceptual-motor slowness, limb control problems and decreased motor proficiency. In general, their motor skills are reported to be below their aged-matched peers, as they are affected by a series of deficits in aspects like timing, maintaining balance, co-ordination, muscle tone and strength (balance being the most affected ability (Carmeli et al. 2002)).

In order to deal with that, the scientific community has recently turned its interest towards VR systems aiming at creating individualized motor training programs that will allow the users (children with DS) to efficiently train in especially chosen tasks that can help them in everyday situations. To this end, video games have been used, as they provide not only real-time practice of tasks and activities, but also allow the users to engage in motor tasks that involve a wide range of sensory feedback, adjustable movement amplitudes, speed and precision levels.

Below we will briefly review the devices that have been used in order to offer a more realistic interaction with the VR systems developed for rehabilitation purposes. Subsequently we will describe in detail which devices the VR system developed within POSEIDON will use.

3.3.1 Literature review

The number of works that tried to incorporate VR systems in the rehabilitation process is rather limited. Nintendo Wii controller and the Microsoft Kinect sensor were two of the main devices that have been used to realistically interact with VR systems specially developed for children with DS. Below we will present complete systems that have been proposed and employ either Wii or Kinect to create a VR system for children with DS.

Wii has been mainly used for rehabilitation purposes during the last five years. Early approaches focused more on proving its effectiveness on the educational/rehabilitation process, rather than on creating a complete and efficient system. Indeed, the study conducted in (Wuang et al. 2011) compared the effect of standard occupational therapy (SOT) and VR using Wii gaming technology (VRWii) on children with DS. The authors assessed a group of children with DS using several measures of sensorimotor functions. The results showed that the group of children that used VRWii had a greater pre–post change on motor proficiency, visual-integrative abilities, and sensory integrative functioning, thus proving the efficacy of using VR systems with Wii as a complementary mean of therapy to achieve rehabilitation in children with DS.

The balance of children with DS was studied in (2005l & Abdel 2010). Three Wii-Fit games were employed in addition to the traditional physical therapy program, for six weeks. The results indicated that the use of Wii-fit games resulted in a high improvement of balance and could therefore be used as a VR-based therapy.

A more recent study (Salem et al. 2012) investigated whether the use of Nintendo Wii SportsTM and Nintendo Wii FitTM, could improve motor skills, by employing balance, strength training and aerobics games. The Gross Motor Function Measure (GMFM) was used to assess gross motor skills a week after using the system. The results highlighted the importance of Wii as a feasible, safe and potentially effective therapeutic tool to augment the rehabilitation of children with DS.

The later release of Kinect sensor, has led to almost no approaches existing that deal with children with DS. Indeed there exists only one approach that employs Kinect to study their patterns of motor behaviour (Alesii et al. 2013). Kinect was only used to film the subjects while playing a snowboarding game in a VR environment. It was therefore used as a data collection mean and did not interfere with the training procedure.

There exist no approaches that combine VR systems with Kinect sensor devoted to children with DS. There is only one approach that combines VR systems and Kinect (Lorenzo et al. 2013) but focused on children with Asperger syndrome. However, the similarities between the difficulties that children with Asperger syndrome have to face and the ones observed in children with DS are rather limited. More precisely, their common characteristics include the disability in proper planning and organising basic activities, the strong resistance to change and the need for specific instructions and visual aids. Therefore, the only result that can be reused for the case of children with DS is that of the confirmed efficacy of using VR systems with Kinect sensors to aid the rehabilitation/training procedure.

3.3.2 POSEIDON hardware

It is essential for the POSEIDON framework to offer many interaction options with the VR system, besides the typical mouse and keyboard devices. Thus, the developed VR system will be able to effectively communicate with the interactive table developed in D4.2 v.1, as well as with a Kinect sensor.

Although the vast majority of already existing attempts employ the Wii Remote to achieve a more realistic interaction with the VR system, the POSEIDON VR system will employ the Kinect sensor for that purpose. The reasons for that choice are threefold:

1) The Wii Remote requires the users to hold a specific controller that tracks the position of the user's hand at any time. With that controller the user interacts with the VR system by manipulating objects. However, the accuracy of the tracked limb is severely compromised by the visibility of the controller. There exist several body configurations in which the controller is out of range and therefore cannot be tracked. It remains unclear what the system will do in those cases, something that is highly undesirable when dealing with people with DS, where a tight control of the environment is required.

2) The Kinect sensor solves the above-mentioned problem, as it does not require the user to hold anything in order to properly function. Furthermore, it is able to track the entire skeleton of the user, and not just his/her hand position, something that can be extremely useful for the user's behaviour recognition (including action recognition, that can lead to identification of stress).

3) The latest version of Kinect sensor (version 2, due this summer) incorporates many exciting features, such as emotions recognition, gaze detection and efficient tracking of more than one people and of their body limbs. All these features can greatly assist in recognising the emotional status of a person with DS, for example if he/she is feeling happy, distressed etc., so that the system can easily adapt itself to better suit its user needs.

Due to all of the above-mentioned reasons, the Kinect sensor will be used as an interaction option with the VR system, along with the interactive table, and the typical mouse and keyboard.

3.4 Software

3.4.1 Literature review

There is no universal solution for building a VR environment for people with cognitive disabilities and typically such systems are built using open sources and commercial software packages. For 3D modelling, software is usually provided by companies such as Adobe and Autodesk. Their packages consisting of Autodesk Maya and Adobe Director usually provide the user with a broad range of robust tools. Open source software allows developers to modify the software for a particular project. For this reason, research groups often used open source software or develop their own. Examples consist of toolkits such as VR Juggler (Bierbaum et al. 2001); a suite of APIs that allow portability between different hardware solutions: XVR (Carrozzino et al. 2005) (eXtreme Virtual Reality - a development environment for virtual and augment reality application; CAVELib – the original API designed for use with the Cave Automatic Virtual Environment (CAVE) which has since been commercialised; and low level interfaces such as OpenGL and MATLAB. Companies that develop programs for VR applications include Dasault Systems 3DVIA product line (including Virtools); WorldViz Wizard – Complete VE solutions and extension libraries such as character creation and position tracking – EON Reality’s family of interactive 3D software packages and Manageable Kinematic Motion MKM, Unity Technologies – a platform for game creation.

3.4.2 POSEIDON software

One of the goals of POSEIDON is to determine the types of difficulties people with DS experience in situations related to environmental learning and to help these people overpass them. The ability to know where they are and to find and trace a route are crucial aspects in their development. We are therefore interested in navigation and route learning in people with DS and we want to investigate these aspects in a VR environment, because it offers a safe alternative to the real world. However, as we wish to ensure the skill transfer from virtual to real world, the VE environment has to be as realistic as possible. Moreover, in order for the training process to be efficient, the user needs to receive realistic navigation information that can be learned after sessions of practice and alternation with the real world.

This section entails an overview of the game development environment and the navigation services that will be used for the developed VR system in POSEIDON. The interface presented in this report is implemented in Unity, a multiplatform game development environment. Unity facilitates fast game development sparing the user the work in creating a content pipeline, a scene graph and more. Its advantages include: content centred development, scripting in C# .NET or JavaScript; immediate mode graphical user interface; development to web player and more. The navigation features are implemented using Google Maps and Street View API as they both provide real world navigation data, which can be integrated in the developed VR system.

3.4.2.1 Unity

The game engines are responsible for everything happening on the screen, from the mathematics to the artwork including rendering, and integrating a control method and a set of rules for the game to follow. The Unity Engine, currently at version 4.5.2 (http://www.unity3D.com) is a multi-platform game engine with multiple features that can be used in the creation of interactive 3D content. The code behind the game engine is delivered with just-in-time compilation using the open source C++ library Mono. In addition to the Mono library, Unity also takes advantage of other software libraries such as Nvidia's PhysX physics engine, OpenGL, and DirectX for 3D rendering and OpenAL for audio.

Applications in Unity can be quickly ported onto Android, iOS, Windows Phone 8, and BlackBerry and the software has also capabilities for development for Playstation 3, Xbox360, Wii and web browsers. Its interface is intuitive, its architecture is well designed and there is a wide range of assets that can be easily reused. The supported assets can be developed in a variety of applications like 3ds Max, Maya, Softimage, Cinema 4D, Blender and this emphasises its flexibility. Thus, compared to traditional development approaches, Unity has evolved as a game engine with a great potential. Moreover, because of Unity's wide use and easiness, several VR companies now fully support it.

3.4.2.2 Vuforia

The Vuforia platform, a product of Qualcomm Connected Experiences enables augmented reality (AG) experiences. Vuforia uses Computer Vision to recognise and track in real-time planar images (targets) and simple 3D objects such as boxes. Developers have the possibility to position virtual objects in relation to the real world images viewed through the camera of a mobile device. The viewer's perspective on the image corresponds with their perspective on the Image Target and it appears that the virtual object is part of the real world scene.

The Vuforia SDK supports both 2D and 3D target types, including markerless Image targets, 3D Multi-Target Configurations, and a form of addressable Fiduciary Marker known as a Frame Marker. Additional features of SDK include localised Occlusion Detection using Virtual Buttons runtime image target selection and the ability to create and reconfigure target sets programmatically.

3.4.2.2.1 Unity extension

The Vuforia AR Extension for Unity allows developers to create AR applications easily by enabling vision detection and tracking functionality. Vuforia AR Extension is compatible with both Unity Standard and Unity Pro and can be downloaded from Asset Store. AR applications developed using Vuforia are compatible with a broad range of mobile devices including the iPhone, iPad and Android tablets.

3.4.2.3 Services – Google Maps and Google Street View

Google Maps has a series of features that can benefit both users and developers. Google Maps and Google Maps Street View APIs provide high resolution aerial or satellite images for most urban areas of the world. Google Maps provides also a route planner with different modes of transportation: driving, public transit, walking and bicycling.

Google Maps Street View provides panoramic 360-degree images that allow the user to explore the world, navigate a trip, and show the outside of a business. Google Maps Street View covers over 3000 cities in 51 countries. Each Google Street View panorama is an image or set of images that provides a full 360-degree view from a single location. The result is a projection on a sphere with the image wrapped to the 2D surface of the sphere. Street View panoramas are identified by either panorama ID or by coordinate. All Street View API applications should use an API key that enables the user to monitor the Maps API usage.

The Google Maps API provides web services as an interface for requesting Maps API data from external services in order to be used in custom applications. These web services use HTTP requests to specific URLs by passing URL parameters as arguments to the services. As a result, these services return data in the HTTP request as either JavaScript Object Notation (JSON) or Extensible Markup Language (XML) for parsing and processing by every application.

The responses provided by Google Web Services are easy to understand, but they need to be parsed in order to extract the values of interest. The parsing scheme depends on whether the output is in XML or in JSON. JSON responses can be processed within JavaScript itself on the client, while XML responses should be processed using an XML processor and query language. However, JSON has the advantage of a lightweight response.

We conclude that using Google Maps SDK for this stage of the project is a good design choice as it provides complex navigation information, it has a mature API, it is developmental friendly and reliable.

3.5 Tasks designed

In this section we will present in detail the tasks that are included in the VR system and are available to: a) the users (children with DS) for training purposes, as well as to b) the carers and family, in order to add material that may potentially assist the training procedure. First we will describe the rationale behind choosing the specific tasks and subsequently the tasks, in detail.

3.5.1 Rationale behind choosing the training tasks

It is infeasible to create a VR environment for every possible place the user (child with DS) will visit. Such a system would not be easily customisable and would not serve its purposes in terms of efficiently training its users. We therefore decided to included tasks that would be general enough, so as to provide the users with a general training of essential everyday tasks, that remain more or less unaffected by different environmental conditions (such as cultural variations etc). In that way we can assist the users in achieving more socially acceptable interactions with their fellow peers, in order to increase their acceptance by society.

Our main emphasis will be given in providing travelling options to the user (child with DS), whether this travelling means commuting for business (to school), or for entertainment (meeting with friends or going for example to the cinema). Our basic aim is to provide tasks that create a safety zone for the user travelling, by proposing safety paths (Alesii et al. 2013). In the future, additional tasks can be added, that will help the children with DS deal with everyday situations (like shopping list, money index book, cookbook (Alesii et al. 2013), etc.).

3.5.2 Selected tasks

3.5.2.1 Contextual reminders

In training people with DS for daily life task, we use both VR and AR technologies to enrich the real environment and to make them acquire knowledge.

One example can be built as a Reminder Application that can help people with DS in preparation before going to a specific place (e.g., going to cinema preparation). The user is scanning items of interest (e.g., her wallet) using a mobile device or tablet and attaches reminders to each of them (e.g., a list of things that need to be taken to school, tickets). All the data is stored in a database that can be also integrated with a calendar application that retrieves the schedule of the day. Hence, users can be helped in various moments of their daily life with information that is not available in the real world and that enhances user's comprehension on the environment.

3.5.2.2 Guidance application

In order to assure a safe navigation for people with DS, the guidance application can be personalised with annotated places inserted by the carers. Using these annotations, when certain places are recognised (based on location and orientation of the person/device), the application displays contextual information about those places. Optionally, support for adding visual information in real time can be provided (e.g., the user can press a button to get additional information about a certain location and the carer will receive a photo, annotate it, and the annotation will appear on the user's device, thus getting the required information). This guidance application can also be used with the planning route application, in order to help people with DS to navigate independently through a real environment.

3.5.2.3 Route planning

The route planning application helps users to get from one point to another. The technologies it could use are VR for home training (see Figure 3) and AR for on the road guidance. The VR environment could provide real navigation information allowing them to explore environments built realistically by using Google Street View API. In the case of the AR application, carers would have the possibility to enrich the environment by taking customised photos (e.g., underground maps displayed at crossroads). People with DS could use the device to detect their location and based on the saved destination, they can be guided through various types of feedback (e.g., arrows, written instructions). Both applications aim at providing at home and on the road support for people with DS, thus assisting their independency. Moreover, the system has also the potential to help their parents or carers in creating a complex learning environment with a variety of features.

4. Technical implications

In this section we will talk about the implications that can occur while building the POSEIDON VR system. These implications are presented by category, based on the main cause of existence.

4.1 Caused by devices

It is quite possible that the devices with which the VR will have to communicate are not compatible. To avoid this issue, we will create a VR system with no special requirements in terms of hardware. It will be able to function properly in a standard desktop PC, connected with a standard screen.

The interaction between the VR system and the user will be achieved using either the typical mouse or keyboard, or using the interactive table. All these devices use hardware that is easily connected with each other, thus no compatibility issues exist. To ensure that no issues will arise, several compatibility tests will be executed prior to releasing the VR system to the user families. These compatibility tests included automated application testing on different versions of Windows operating systems via VMware Workstation.

4.2 Caused by software

As mentioned earlier, the VR system will comprise of versions for different operating systems (e.g., Windows, Mac OS).

The VR system (and all of its versions) is a stand-alone application that can be downloaded and run on any computer. The user needs to have a POSEIDON account to be able to access routes and information created with the POSEIDON app for navigation.

4.3 Caused by specific needs of the users

Each person with DS is different and may have different challenges. It is therefore impossible to create a VR system that will be addressed to every user. Indeed, some children may be more capable than others when it comes to using technology (even the standard keyboard and mouse devices). Others may exhibit severe lack of coordination skills, which in combination with the poor motor abilities observed in children with DS can make them unable to use a Kinect sensor or an interactive table.

Since a system that satisfies all of the users' needs cannot be created, the developed VR system will be fully customisable to the user's specific abilities and preferences, offering a variety of choices. For example, if the user exhibits a severe lack of coordination in his/her actions, the interaction using the standard keyboard and mouse devices will be offered. For more 'advanced' users, the Kinect sensor or interactive table options will be available.

By providing several interaction options with the VR system, the implications caused by the user’s needs can be dealt with (up, of course, to a certain extent). As we are unable to predict the user's behaviour and severity of his/her condition, we will offer additional functionalities or interaction options as different choices to the VR system, so that each user can customise it to his/her needs and preferences.

5. Protocol followed for testing the VR system

Technology design needs to consider a set of cognitive and physical abilities to achieve optimal performance. A 3D representation of a real environment might fail to communicate effectively to people who do not have the ability to abstract concepts and worlds. In order to upgrade the lives of some, technology has to be designed for diversity and ability. In developing useful technology, there are several phases to consider: design, development, testing and publishing. Usually, the stakeholders are just considered in the testing phase. However, when the aim is to increase independence of people with special needs, a continuous involvement of both, developers and stakeholders, is necessary for creating a valuable product. Because of the varying range of capabilities and difficulties of the target population, developers needed to maintain an updating loop of the proposed solution, in which they consider the feedback of a significant number of stakeholders. In POSEIDON we used an iterative co-design methodology that brought together all the involved stakeholders (primary users, caregivers, therapists and developers). We involved stakeholders through a variety of activities. These include questionnaires, interviews, project pilots, workshops with primary and secondary users as well as with the Project Advisory Committee.

Initially, we wanted to understand and be able to conceptualise the needs and specific issues of the stakeholders. Then, we produced solutions that address the observations we made in the first step. To validate the design and content of our proposed system, we asked stakeholders to use and experience it. All these sessions were analysed in detail in aspects related to functionality, user interaction, and quality of experience. Each interaction of the users with our system brought new insights about our stakeholders through this analysis, but also through the provided feedback.

It is important to highlight that the organization of the different events which facilitated interaction or gathering of feedback from stakeholders were organized mostly following the lead of the Berlin Institute for Social Research (BIS), one of the partners of the POSEIDON project. Although the type of interactions to have, their frequency and their timing were planned and agreed with most of the partners of the project, BIS provided the protocols of interaction with the stakeholders, especially the documents, including surveys, to use when presenting and gathering information from stakeholders

5.1 Questionnaires/Interviews

The aim of this phase was to assess the requirements of people with DS and to bring up any significant issues that need to be addressed. The requirements analysis was done using different methods: questionnaires (people with DS and caregivers) and face to face interviews with the stakeholders. The Berlin Institute for Social Research conducted an initial web-based questionnaire to almost 400 parents, from three different countries. The answers were used to analyse the type of technologies people with DS use, the level and type of support they need when interacting with these technologies. Additionally, focus was put on their living situation to identify how they travel, manage time, handle money and communicate. All this information was used in proposing a set of scenarios and personas that were meant to illustrate the aspects targeted by. The scenarios presented characteristics and possible daily activities of people with DS from different countries.

5.2 Workshops with Primary/Secondary Users

The first project workshop took place at the beginning of the project. Different technological solutions were presented to the primary users (VR games controlled through wii control, mouse/keyboard or tablet). The aim of this interaction with people with DS and caregivers was to explore user engagement with our training system and their quality of experience.

These initial observations were used in creating a mock-up of the system with a set of proposed interaction methods. This first prototype was introduced to the users during a workshop that took place in Mainz, Germany in month eight with participants from five countries. We conducted a set of experiments with PUs over two days with the intention of assessing: the usability of our first prototype, the advantages and disadvantages of using specific proposed technologies: VE, interactive table interaction. This workshop was followed by a series of shorter workshops (half a day long), held primarily in London, additional ones also in Germany and Norway. These events were meant to facilitate the design of the products functionality and interface. Developers participated in these meetings in order to gain a deeper understanding of the necessary modifications.

5.3 Project Pilots

Over the course of the POSEIDON project, there were two pilots of one month each, and a single day extended pilot. These pilots were carried out in the UK, Norway, and Germany. During the month long pilots, three families from each of the countries were selected to participate in the evaluation. The process involved screening of potential families through a questionnaire, to check on their suitability for the pilot. Once the families were selected, users were given diary sheets, as a way of documenting their use of the POSEIDON system. Main topics were: who used it, what they liked and did not like. Each family received four visits. In the first visit project developers and Down Syndrome Association (DSA) monitors went to get to know the families, establish a good relationship with both PU and SU. Information sheets, and consent forms were distributed and filled in. Following this, the Home Training of Navigation Services application, POSEIDON Mobile application, POSEIDON Context Reasoner and Carers web were installed and setup for the users. Over the course of the pilot, different interviews, and questionnaires were completed to gain feedback of the different systems. Moreover, usage of applications was logged, which allowed us to see how many times the users used each component of the system and how they benefitted from it.

For the extended pilot, in a similar fashion, different day events were held in all three countries. A total of 26 people with DS took part with 10 in the UK, 13 in Germany, and 3 in Norway. During the extended pi- lot there were three items we wanted to evaluate new functionality added to the different systems including more contexts being handled in the POSEIDON mobile application, a new learning and assessment mode

In the Home Training of Navigational Services, and further tests of the Money Handling application. All these events allowed for a prolonged utilisation of our solution. Stakeholders were able to integrate its functionality in their daily lives and to choose the frequency of using the provided services. A quantitative summary of these activities is given in Table 5.1 whilst a qualitative overview is provided in Figure 5.1.

Our proposed method of co-design based on continuous feedback from the stakeholders and of triggered adaptations of the product allowed the developers to maintain a strong connection with the stakeholders. Moreover, developers gained a better understanding of the way primary users are interacting with different features.

ID	Type of Involvement	Month Number Number	No. of Main Stakeholders Involved
W1	Workshop	2	5 PU 5 SU
Q1	Questionnaire	2-4	400 SU
W2	Workshop	10	5 PU 7 SU
A1	Advisory Committee	12	3 TU/O 4 SU
W3	Workshop	14	13 PU
P1	Pilot 1	20 - 23	9 PU 9 SU
P2	Extended Pilot	25	26 PU
A2	Advisory Committee	26	3 TU/O 5 SU
P3	Pilot 2	31	9 PU 9 SU

Table 5.1 User Engagement Activities during POSEIDON

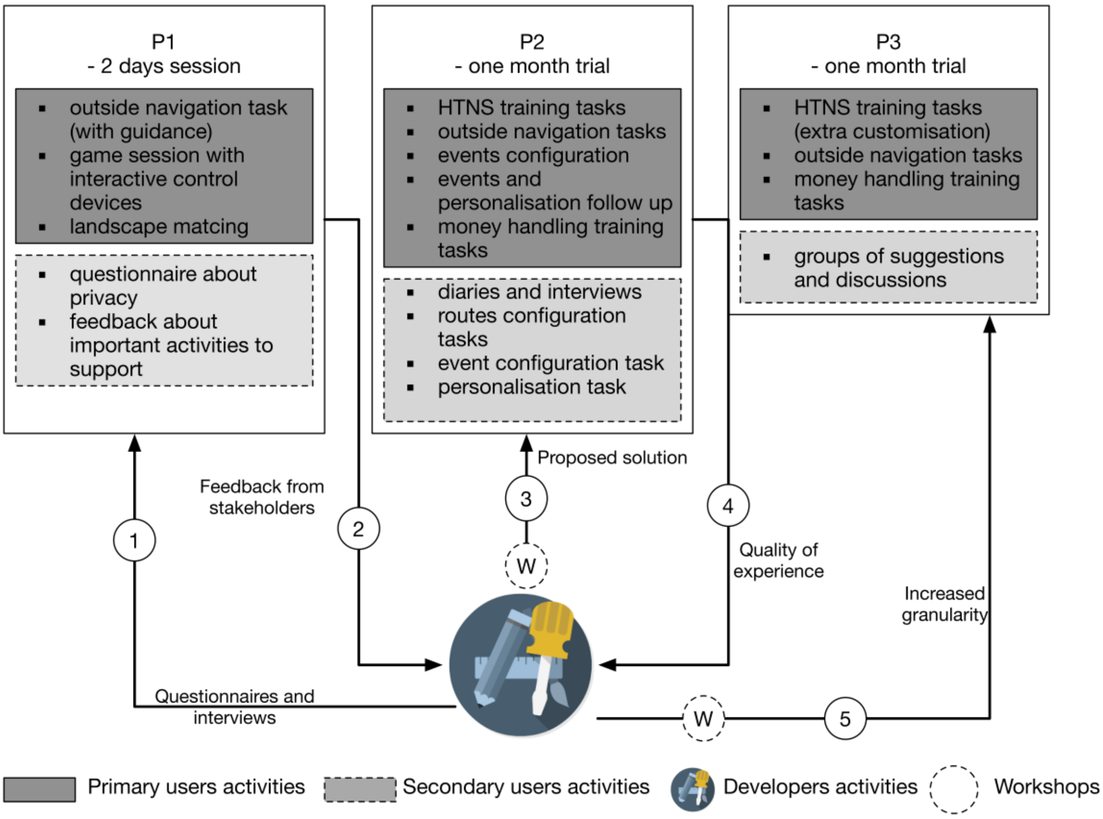

Figure 5.1 Diagram of the stakeholders – Developers Co-design Interaction Activities

5.4 Service Refinement and Evolution

Our method is based on several small and big project iterations and frequent interactions with stakeholders. In this section we explain how the POSEIDON concept, in the form of successive prototypes, was being shaped through the different stages of the U-C IEDP method. Figure 5.2 shows how they happened in time.

5.4.1 Prototype One

Initial Scoping: As central to all the main loops our method, we started gathering the expectations of the stakeholders. Initially, this happened in form of a questionnaire (Q and U1) to people with DS and their carers. This gave the team feedback about the activities to support. It was found that the participants were often quite capable of carrying out different tasks, including navigating, if with some support. It was felt that areas of achievable tasks with assistance were likely to be a more successful target of development. The first workshop (W1) covered the stages for defining Required Services and defining required Intelligent Environment (IE) infrastructure from our method. The technical teams translated the information gathered from the stakeholders into services that were useful for them, during the first workshop. Developers proposed a set of services to support the main activities in which people with DS required help, according to the questionnaire. The questionnaires were also discussed to determine the most suitable technology for people with DS and their parents, selecting the devices and interfaces that materialized the IE. Finally, a requirements document was produced, as a contract between all the stakeholders, defining what POSEIDON would do. After the first workshop, the teams prepared the initial design and started preparing the first prototype. Based on related work, developers mocked up a potential future state of the system.

Main Development: This first design was discussed in a technical meeting in month 5 with initial ideas. The teams gathered both feedback and suggestions from the national Downs Syndrome Associations based on these ideas. Based on this feedback the development teams identified areas that needed to be refined, defined and clarified. In the second workshop (W2), the developers introduced a mobile navigation system, using Google Directions for route data. This data was supplemented with photos of the specific Google way- points, in an effort to see if photos helped them navigate. A racing game was also developed for use with a large smart table, as a way to assess the participants motor skills, and whether they find the interaction de- vice enjoyable to use.

IE Installation: The second workshop also covered the whole IE Installation loop of our method. The users were instructed on how to use the system. The event was held in Mainz, Germany including 5 people with DS. Some of the feedback highlighted the need of considering time management. During the second workshop, the prototype was tested in order to gather feedback about the Primary Users using the devices. It was found that using automatically generated directions from services including Google Directions did not give sufficiently understandable directions for navigation. Based on this finding, it was decided that secondary users should have the ability to decide their own routes, using their own decision point photos, and textual commands. Using textual commands, the secondary users can generate additional information that can be useful to the primary user including what side of the road to be on, whether to cross at particular places etc. It was found also that the PUs enjoyed using the smart table touch device as an interface device.

5.4.2 Prototype Two

Initial Scoping: As input for the initial scoping, during the interview to the stakeholders, the families presented daily activities of primary users with an emphasis on areas where they need more support.

Main Development: For prototype two a number of changes had been added to the POSEIDON sys- tem. First, routes for the user could be designed in the **Home Training of Navigation Services** application by the secondary user. This allows secondary users to tailor the routes by adding custom waypoint instructions, and photos to assist the primary user. These routes are then synchronised to the main POSEIDON application using POSEIDON webservices.

IE Installation: Prototype two was tested during Pilot 1 and Extended Pilot 1 (P1 In the **Home Training of Navigation Services,** it was decided that additional steps should be addable to a route, instead of just editing the Google given instructions.

Figure 5.2 shows some of the activities carried out during our stakeholder engagement activities. Figure 5.3 illustrates how the main milestones of the projects were met. There, we present the interactions between stake- holders and developers and how these led to an increasingly mature system. Theoretical assumptions were thoroughly tested in different ways with different categories of stakeholders. The observations, suggestions, results of every interaction was analysed by developers with different outputs overt time.

5.4.3 Prototype Three

Initial Scoping: Pilot one questionnaires were used as the first stage of the initial scoping in our methodology, Interviewing the stakeholders. During the pilot one, the users demanded more personalization possibilities when defining a route (Insufficient number of decision point provided by Google Directions). Taking this feedback from the stakeholders, the developers redefined the required services to have a new approach for route creation.

Main Development: For prototype three, a new version of the POSEIDON navigation application was introduced with further improvements to navigation and calendar handling. An application for creating routes was developed for mobile devices. This was due to added complications in making the user create the routes on a static computer at home. With the route creator application, the SU can walk the intended route, taking photos, and automatically tagging decision points with their current location. An updated version of the **Home Training of Navigation Services** was developed to include the ability to add new decision points to routes, add voice commands, and further assessment modes to allow the PU to train a route more. The routes can be created either on the phone or in the **Home Training of Navigation Services** app. In any of these cases, a more grained customisation can be done only in the **Home Training of Navigation Services** app.

IE Installation: Prototype three was tested during the final Pilot 2 of the project. The pilot was used to validate the equipment, software and other services. Over the course of the pilot, there were indications of users favouring particular services, especially the application for route making, and main navigation application. Particularly, secondary users enjoyed the ability to easily customise the route with their primary users, adding photos, and customised instructions.

The training was positively evaluated, the primary users enjoyed learning and playing and they managed to remember more easily particularities corresponding to each route.

Figure 5.2 Interactions with Primary Users

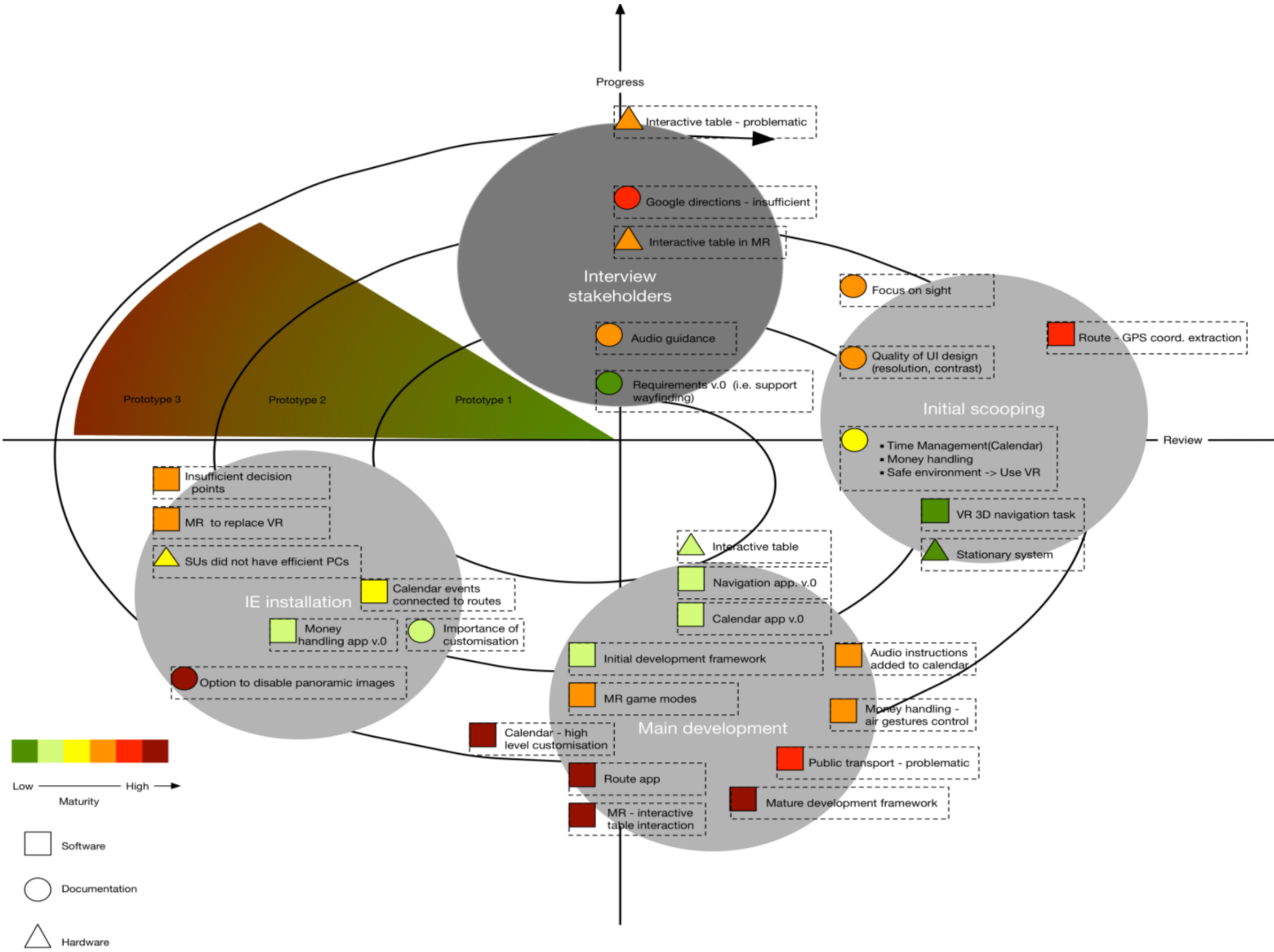

Figure 5.3 Home Training of Navigation Services evolution through iterations

6. Conclusion

In this deliverable we have presented the **Home Training of Navigation Services** developed within POSEIDON that tried different approaches for training people with DS, from totally virtual to a realistic experience enhanced with virtual elements.

In this document we first justified the use of VR as a rehabilitation tool, especially useful for the cases of children with DS. We proceeded with presenting the initial strategy followed for creating the first version of the VR system. In more detail, we discussed about its hardware requirements, its key functionalities, as well as which devices and software were used for this version. We also analytically presented the list of representative tasks that were designed as part of the training procedure.

We further covered the possible implications that may occur due to hardware and software issues, as well as due to the very nature of users (children with DS), that makes it impossible to create a system suitable for all. We thoroughly described the methodology and the results obtained as results of the evaluation.

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