

# Dimensions of Mobile Augmented Reality for Learning: A First Inventory

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## **Dimensions of Mobile Augmented Reality for Learning: A First Inventory**

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### **Abstract**

This article discusses technological developments and applications of mobile augmented reality (AR) and their application in learning. Augmented reality interaction design patterns are introduced and educational patterns for supporting certain learning objectives with AR approaches are discussed. The article then identifies several dimensions of a user context identified with sensors contained in mobile devices and used for the contextualization of learning experiences. Finally, an AR game concept, “Locatory”, is presented that combines a game logic with collaborative game play and personalized mobile augmented reality visualization.

### **Keywords**

Augmented Reality; Locatory; Mobile Learning

### **Towards Mobile Augmented Reality**

Until recently, augmented reality (AR) applications were mostly available for powerful workstations and high-power personal computers. The introduction of augmented reality applications to smartphones enabled new and mobile AR experiences for everyday users. Because of the increasing pervasiveness of smartphones, AR is set to become a ubiquitous commodity for leisure and mobile learning. With this ubiquitous availability, mobile AR allows us to devise and design innovative learning scenarios in real world settings. This carries much promise for enhanced learning experiences in situated learning. In the present article, we look at different dimensions of mobile AR and exemplify their potential for education. At the end, we report on a short experiment that we conducted, called Locatory. It exceeds the current state of art for common mobile AR applications by introducing interactive and collaborative elements as well as gaming mechanisms.

Milgram and Kishino (1994) describe augmented reality (AR) as “relating purely virtual environments to purely real environments” (p. 1321). Rice (Shute, 2009) gives an even broader perspective on augmented reality, stating that it should cover any media that is specific to your location and the context of what you are doing. We find these definitions too generic and in direct conceptual conflict with closely related systems such as context-aware or immersive systems, mixed reality, and personalized adaptation.

For the purpose of this article, at least, we therefore want to specify augmented reality as a system that enhances a person’s primary senses (vision, aural, and tactile) with virtual or naturally invisible information made visible by digital means. A key defining factor in this is the synchronization that the system requires to perceptually embed the information into the enhanced (re)presentation of the world view – where ‘view’ also includes other primary human senses.

In this context, examples of virtual information include information artifacts like geo-located meta-information, visual/audio overlays, or 3D enhancements. Naturally invisible information, on the other hand, includes things that the human senses do not register, e.g. compass orientation, invisible light (infrared, ultraviolet, X-rays, etc.), ultrasound, or barometric pressure.

Like context-aware systems, augmented reality applications make it possible to filter information and present information overlays relative to the user's current context (Zimmermann, Specht, & Lorenz, 2005; Zimmermann, Lorenz, & Oppermann, 2007). Information in context can be filtered according to location, movement path, facing direction, object in focus, time period, or meta-information such as the learner's personal interests or profile. As we demonstrate below in our experiment, Locatory, information can also be filtered in a social context as relative to surrounding peers and their activities. Furthermore, we define mobile augmented reality as a specialization of context-aware systems, as there is a close synchronization of existing human senses and perception with the digital information channels presented in augmented reality.

In addition to this conceptual model of AR applications, an engineering perspective is required to understand the technical components and their role in mobile AR systems for learning. In their description of the history of mobile AR, Wagner (2009) has identified the following technical components of mobile AR systems as being important:

- *Flexible display systems*, including head-mounted display systems, camera phones, and handheld projectors. Display technologies are becoming increasingly more flexible and cheaper to produce. These technologies enable the augmentation of everyday vision of mobile users.
- *Sensor systems* in mobile devices like gyroscopes, GPS, electronic compasses, cameras, and microphones, as well as indoor location tracking systems.
- *Wireless networking protocols and standards* supporting indoor and outdoor augmentation settings. These also enable multi-user real-time interaction in the augmented reality.
- *Mobile phones* with computational power to do real time visualization of 3D objects and overlays on a standalone device.
- *Tagging and tracking technologies* with six degrees of freedom, multi-marker tracking, and hybrid tracking systems. This technology is also related to one of the most researched areas in AR, the registration problem (Bimber & Raskar, 2005), which is the challenge of linking the real-world perception of a mobile AR user and the presentation of the augmentation layer. Thus, the registration problem is closely linked to what we refer to as synchronization.
- *Linking of location-based AR information* in storytelling and gaming approaches. There is an urgent need when AR is used for learning support to link AR experiences with instructional designs or at least with task structures and sequencing approaches. Storytelling and gaming approaches are currently the most prominent approaches.
- *Flexible layer-based AR browsers* with integration of social media. Basically, AR systems must also build on existing information channels and can present existing information to users in a new kind of user interface. Therefore, implementations of mobile AR for learning must enable open interfaces to existing content and services.

Specht (2009) describes a generic model for ubiquitous learning and synchronizing real-world environments with augmentation media and media channels. In the Ambient Information Channel Enrichment (AICHE) model, five parameters of context are used to synchronize and augment the user's context with information and services. These five high-level categories of contextual parameters are location, time, environment, relations, and ID. Furthermore, the role of sensors and sensor information is defined as essential to connect media and real world objects for situated learning experiences and the support for reflection in action and about action (Schön, 1983). Mobile devices today typically come with a range of basic sensors. Through processing and aggregation of the raw sensor data, higher-level sensors and semantic classification of raw sensor data can be implemented. The AICHE model defines four processes by which sensor data can be a) *aggregated*; and b) used for *enrichment* of physical artifacts and metadata for media channels; c) media channels, artifacts, and users with contextual metadata are

*synchronized*, and d) synchronized information channels are *framed* for metacognitive learning processes.

### *Aggregation*

For achieving contextual learning support with sensors it is important to aggregate sensor information to make it meaningful for the learning objectives or tasks at hand. As an example, the location of a GPS device carried by a user is only meaningful when it is connected to the user's perceivable environment and relevant learning tasks. Aggregation can be a quite simple process, linking together different sensor information such as the time of day and location of a GPS sensor. In most cases aggregation is also related to the conversion of raw sensor data into defined categories and scales, but it can hold quite complex algorithms of sensor input as researched in sensor fusion as well.

### *Enrichment*

In this process, artifacts, channels, or users are enriched with aggregated sensor information. Enrichment is mostly based on a specified mapping, which links an attribute of an entity to a raw data stream. Via such mapping, devices and users also know which sensor data is relevant for them and what information should be delivered to them. As a consequence of the enrichment process, each artifact, user, and channel is enriched with context metadata.

### *Synchronization*

In the synchronisation process, the enriched users, artefacts, and channels are synchronised based on a described logic. As an example, the location of an artifact and the user are used to display a channel via an artifact. Synchronisation is at the core of every contextualised learning support. It is the result of a matching process, i.e. the user location is matched with location metadata of channels and artifacts. It is also evident that synchronisation is based on instructional designs specifying the logic of the matching.

### *Framing*

Additionally, the display of the synchronised channels can be contrasted with relevant reference information in the instructional design. The framing process is mostly related to feedback and stimulation of metacognitive processes. Especially with augmented reality applications for contextual support, framing gets an important role as most artifacts and real-world objects with which we learn need to be framed in the instructional context.

## **HCI Interaction Patterns for Augmented Reality**

Lamantia (2009) describes several forms of HCI patterns for mobile AR, which include heads-up display, tricorder, holochess, and x-ray vision. These interaction design patterns are the underlying structures that form mobile AR experiences. We will use these here to analyze educational AR applications.

### *Heads-Up Display (HUD)*

Heads-Up displays (HUD) project information into the visual field of the user and have, so far, mainly been used for navigation or additional information necessary in the course of action. A HUD is the oldest AR interaction pattern and was introduced in the 1950s. Using a HUD in the cockpit of a fighter-jet, pilots can read information without having to move their eyes to a special instrument panel.

The main characteristics of this interaction pattern are that a user does not take his/her eyes from the environment to an instrument panel, and information is integrated with the visual field of the user and is synchronized with the movement of the head. As such, a HUD is typically an integrated system. Whereas

many AR tools rely on handheld monitors, a HUD is typically integrated into another existing device (e.g. a helmet, a plane, or a car).

HUD applications can project information on senses other than vision. An audio HUD AR system can inform the user of the environment using a headset. For example, the LISTEN project (Eckel, 2001) immersed the user in 3D audio scenes synchronized with the movements of the user. One of the most challenging problems hereby is the synchronization of the audio rendering with the physical movement of the user. With newer smartphone devices, apps enable mobile phone users outdoors to experience audio augmented reality. By using headphones, the user is not limited in his interaction possibilities and can freely move both head and hands.

### *Tricorder*

The tricorder was introduced in the Star Trek science-fiction television series (1966-1969; <http://en.wikipedia.org/wiki/Tricorder>). It is a mobile device that can scan an environment and provides information about that environment. For example, after landing on a new planet, the tricorder was pointed in a certain direction and would then present a detailed examination of living things present in that direction.

The tricorder-style interaction pattern provides the user with information about his surroundings and the objects in that environment with the help of a screen. A key characteristic of this pattern is that the tricorder is a handheld device. With this device (e.g. a smartphone) the user waves in the direction of interest. This pattern builds on an experience in the real world and allows the user to get additional information about his/her environment via augmented reality.

Tricorders are different from a HUD in that users employ a handheld device instead of an integrated system such as a HUD. Therefore, a tricorder introduces interaction constraints, as the user needs at least one hand to utilize the device, thus constraining a user's movements. The tricorder pattern is very important for mobile devices, and most of today's mobile AR applications are built on this pattern to display points of interest.

In contrast, the decoupling of the AR display from the user's viewpoint also enables different perspectives on presented content and explicit selection of perspective by the user. This type of use is closely related to the holochess pattern, which is discussed next.

### *Holochess*

Holochess is the name of the chess game in Star Wars. The holochess interaction pattern places virtual objects in the real world. These virtual artifacts can often interact with one another or with objects in the real world. Although mobile AR applications have properties of both holochess and tricorder, the most important difference is that in holochess the virtual object is the object of interest, while with the tricorder the object serves as an enrichment of what the user is looking at.

The holochess patterns can be realized with stationary and mobile devices. Recent research also mixes real-world object manipulation and approaches based on automatic scanning of tagged objects. This especially enables integration of tangible interfaces and simulations, and recent research has shown the efficiency of these approaches in vocational training (Do-Lenh, Jermann, Cuendet, Zufferey, & Dillenbourg, 2009).

### *X-Ray Vision*

In the x-ray vision interaction pattern, surfaces can be looked through or underlying structures can be visualized. On one hand, this can be realized in combination with different patterns such as tricorder or

HUD; on the other hand, x-ray vision extends these patterns as the augmentation is in most cases based on high precision registration. Most applications of x-ray vision nowadays can be found in the medical domain.

### Educational Patterns and Practices

(Mobile) AR can be applied in various educational domains. It can help learners to gain a deeper understanding, experience embedded learning content in real world overlays, or explore content driven by their current situation or environmental context. Most prominent examples support exploration of the physical environment with different topics of interest, e.g. history, arts, technology, biology, astronomy, and others, or by enriching artifacts in the physical environment with AR techniques. In general, AR technically is divided in marker-less and marker-based AR to register digital content for real world orientation and placement. In this section we describe a number of educational patterns that are related to the interaction patterns discussed earlier. The patterns described below connect an educational objective to the usage of certain dimensions of context (Specht, 2009) by synchronizing the augmented reality layer with real world learning situations. They are therefore positioned via these connection points in a matrix (Figure 1). We elaborate on the patterns with several empirical examples and findings that are associated with each.

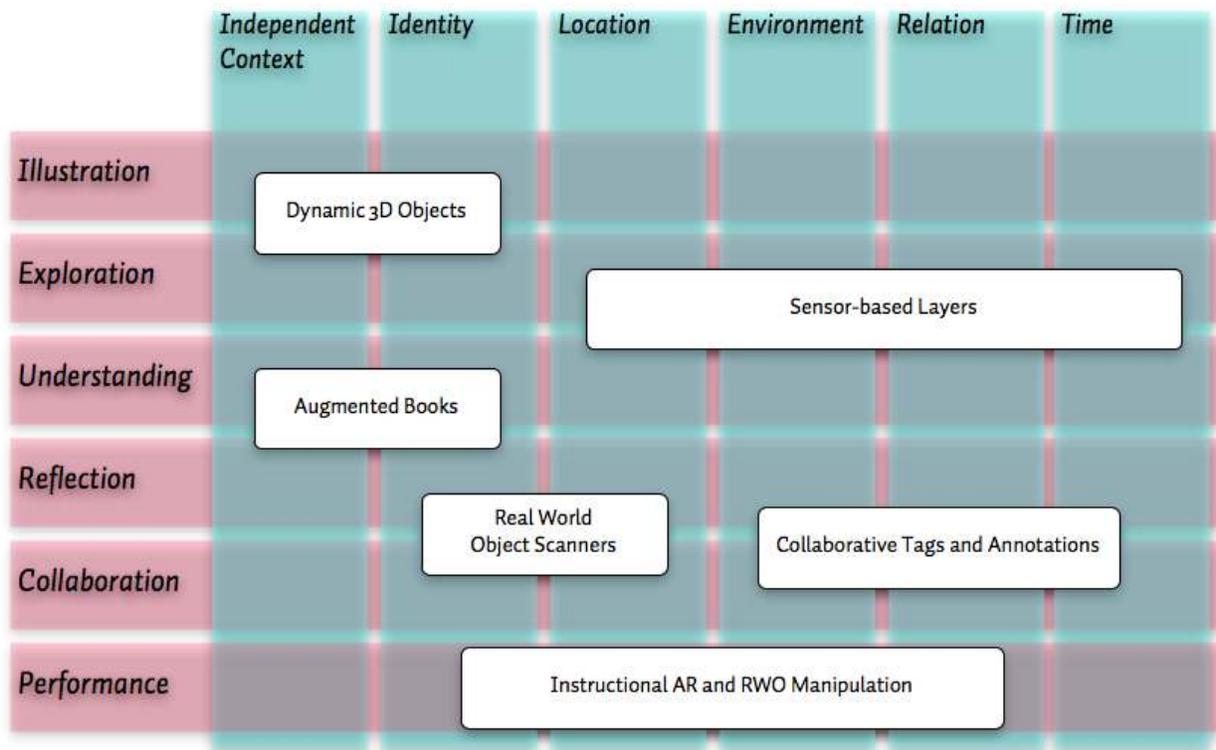


Figure 1: Matrix Classifying Educational Patterns for Mobile AR Based on Educational Objectives and Context Information

#### Dynamic 3D Objects

*Education objective:* Illustration and interactive 3D visualization of learning content, which can be explored from different perspectives.

*Implementation and context:* In most cases, the pattern is implemented by using markers that identify the content to be displayed.

*Examples and evaluations:* Several examples in the literature use the power of dynamic displays embedded in mobile devices or with stationary screens to visualize 3D objects to illustrate the relation between 2D objects and 3D objects or relevant 3D concepts (Hagbi, Bergig, El-Sana, & Billingham, 2009). Martin-Gutierrez et al. (2010) used AR visualization for training of engineering students on spatial engineering tasks and measured a positive impact on spatial abilities. According to Dede (in Blagg, 2009), AR approaches generally enable multiple perspectives on 3D objects as a more immersive and situated perception of complex spatial shapes. Schmalstieg and Wagner (2007) found that an AR system for mathematics and geometry education encouraged experimentation by students and improved spatial skills. While the simple examples mostly do not need an exact mapping on real world objects, like visualizing an object on a table, the more complex examples need extensive registration and linking of the augmentation and the real world objects. Dynamic 3D objects are also used in collaborative scenarios for stimulating discussion and collaborative construction.

### *Augmented Books and Real-World Object Scanners*

*Educational objectives:* Illustration, reflection and dynamic materials addition, deeper understanding through additional perspectives, and extending user senses or perceivable perception range.

*Implementation and context:* Augmented books and objects are the simplest form of relating real-world objects and digital augmentations. In principle, these can be done by manual identification of objects via number codes, with camera based phones using visual codes. There are two possibilities for displaying the augmentation: a) with a mobile device identifying the augmented object, with the mobile device showing the augmentation to the user; and b) with stationary devices, where the users carries and manipulates real-world objects while ubiquitous camera systems follow the objects and their orientation, rendering the augmentation on a screen. Mostly, these augmentations use the identity context to link augmentation and printed material. Newer approaches also enable object recognition via the built-in camera and filter the relevant information, like for example [Google Goggles](#).

*Examples and evaluations:* Via the integration of markers in books, different augmentations can be achieved and applications for more immersive book experiences or illustration of 2D static media with dynamic 3D media can be implemented. Dias (2009) identified several effects when using augmented book approaches, such as enhanced perceived values of learning material, educational illustration, and better understanding of text material. Furthermore, the linking with real-world objects can also be used for collaboration and object annotation, for example in urban design (Wang, Chen, Gong, & Hsieh, 2007).

### *Sensor-Based Layers*

*Educational objectives:* exploration support, immersion support.

*Implementation and context:* Sensor-based layers extend the perceivable information of users based on sensor information. Either the sensor information is embedded in the viewpoint of the user or it is used to filter available information such as underlying geo-tagged information databases. In location-based information layers, the current user location and direction is employed to filter information objects and present maps or camera overlays with selected information. Most popular approaches are based on augmented reality browsers like [Layar](#). From an educational perspective this is strongly related to the inquiry-based approaches to learning support.

*Examples and evaluations:* Mulloni, Dünser, and Schmalstieg (2010) compared different user interfaces combining AR and classical map search interfaces for real-world search tasks. The most efficient solutions for well-defined searches on location-based information have been the “zoom interfaces” combined with direction highlighting based on compass.

### *Collaborative Tagging and Annotation*

*Educational objectives:* Knowledge sharing and awareness.

*Implementation and context:* First approaches on collaborative augmented reality can be found using location-based environments where users can collaboratively annotate and tag real-world objects and share this information with others. Furthermore, first approaches also embedded shared artifacts in AR games that support the collaborative manipulation of 3D objects.

*Examples and evaluations:* Nilsson, Johansson, and Jonsson (2009) used this in the collaboration between different stakeholders in a crisis management scenario like rescue services, the police and military personnel. They found positive effects on efficiency of cooperation and users perceived added value.

### *Instructional AR for Real-World Object Manipulation*

*Educational objective:* real time feedback, linking movements, and AR feedback systems.

*Implementation and context:* Quite fine granular registration of real world overlays is needed for complete instructional environments in AR.

*Examples and evaluation:* As far as the manipulation of real world objects is the objective, good examples are maintenance support systems like the [BMW augmented reality system](#) (Interone Worldwide, 2010). Kotranza, Lind, Pugh, and Lok (2009) used direct visual feedback to enhance task performance on joint psychomotor-cognitive tasks.

### **Locatory: A Case Study of Game Logics and AR Layers**

In most of the examples we found in our analysis, a linking of the current user situation and their actual context has been done, but very few cases link more complex scenarios with sequencing of learning content or guide learners with augmentations to either new augmentations or other real-world objects related to another learning interaction. We therefore aimed at the implementation of *simple sequencing and game playing rules* for a prototype. Second, in most cases we found in the literature, the focus of mobile AR was on individual user views of AR layers, with fewer possibilities for AR object manipulation. Therefore, we aimed at a multi-user scenario in which shared artifacts in augmented reality layers can be manipulated by several users, and each user gets a personalized view of the AR layers depending on their own actions and the actions of other users. Third, as a requirement for reuse and simple instantiation of mobile AR learning support we aimed for the creation of a framework in which different game boards or scenarios could be implemented easily.

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The game concept of Locatory is fairly simple and resembles game elements from the well-known Memory® game by Ravensburger. Players can compete by means of collecting virtual cards that are distributed within an AR layer connected to a real-world campus. Just as described in the tricorder pattern, a player can examine the environment through the camera feed, on which virtual cards are projected. Cards only appear when users are closer than 80 meters to their geotagged location and only if other users have not taken them before. Hence, a user must walk through the game (and its related physical environment) in order to discover and open not-yet-collected cards. Locatory implements a scenario where a game logic is combined with a simple AR location-based information approach. Depending on the state of the game, different AR scenes are rendered for different users. This contrasts with AR browsers such as Layar and Wikitude, where information usually remains static as every user will get an equal AR view for a location. In Locatory, users can gather pairs of cards and then drop these on real-world locations. The concept of the game is to gather cards and match these cards with images of their actual counterparts in the real world.

Users can flip Locatory cards by touching them on the mobile device display (Figure 2). After flipping a card, they see the backside that holds an image. If a user consecutively flips two different cards holding the same image, the card is removed from the game and is added to a user's private 'backpack' or stack. Other players will, from this moment on, no longer see the card in their augmented reality. This illustrates how a user action in AR results in a different AR world being rendered for all other players. The player who took the card can open it from his backpack and then gets one chance to drop that card near a drop point. If the card is dropped close enough to the right drop point, the user is rewarded a game point. Therefore, users have to learn about locations of objects and memorize card locations in the AR game. The game also implements competitive activities in a mobile AR application and personalized rendering of AR scenes.



*Figure 2: User Viewing a Card (Left) and a Flipped Card (Right)*

### *Game Set-Up*

Locatory comes with a simple authoring tool, a Google maps mashup that enables creators to define the positions of cards and drop points. Following game creation, an instance of the game can be played by scanning a QR-code. Scanning a QR-code by means of the integrated camera provides an easy way to launch a URL that starts the game on the smartphone. The URL resolves to an OpenGamaray dimension – an XML document with MIME type 'application/gamaray-gddf'. Via this MIME type, the Android browser can automatically launch the Gamaray client to render the dimension.

### *Formative Evaluation of the Prototype*

Locatory was played at the Heerlen campus of the Open University of the Netherlands. Each time, four teams played the game. Although we don't have quantitative data for these pilots, some interesting findings were made.

Locatory was played at the Heerlen campus of the Open University of the Netherlands. Each time, four teams played the game. Although we don't have quantitative data on these pilots, some interesting findings were made.

*Mobile players were all very enthusiastic about the tool.* Most of them had never worked with AR tools before. Even so, the use of the tools was quite intuitive, and as soon as the basic rules and interaction principles had been understood users could play independently.

*The personalized AR views fostered competition and engagement in the game play.* The personalized view on the AR layers and the fact that visibility of artifacts changed over time affected by the user's interaction or the other players' actions engaged users in a competitive exploration of the game board.

*Creation of customized game boards was fairly easy.* Furthermore, the simplicity of creating new game boards was evaluated with school kids of a secondary school, aged 14-17. In a one-day session, three pupils were introduced to the basic principles of Locatory and created their own game on our campus. They basically had to understand and edit an XML file describing the cards on the game board and their relationship to drop points.

*Locatory absorbed all of the attention of the users,* which might lead to dangerous situations. Although the game was played with adult users, while playing the game, observers had to point out the dangers of cars entering and leaving the parking lot. We found that the way users perceived the game environment relates to tunnel vision. Users were discovering their surroundings by means of the smartphone camera. By holding the smartphone in front of their eyes like spectacles they could gaze at the virtual artifacts. In a location-based learning setting, for example a city trip, this technique may be less suitable as eventually we want users to use their eyes to look directly at the environment.

Our findings with Locatory triggered reflection on AR usability patterns. Therefore, for a follow-up field study we decided to explore the effects of an alternative HUD interaction pattern, which can be realized using a smartphone rendering an audio augmentation layer. Providing an audio augmentation channel to a user has the advantage that users do not need to continuously gaze at the device but by carrying the devices in their pockets and listening to audio they have both hands and eyes free.

### **Conclusion**

In this article we provided an overview of technical components of mobile AR systems, types of user interface approaches for mobile AR systems, the relation between context-aware computing and mobile AR, and the link between educational objectives and context information identified via sensors in mobile devices. Linking of educational objectives and contextual information for synchronization of learning support in mobile AR applications is essential for understanding the underlying learning processes and the role of the augmentation for learning. We hope that the presented overview can help mobile AR researchers and developers to more systematically evaluate the potential of mobile AR for learning and its educational effects. Furthermore, we presented our own prototype, Locatory, which extends some of the work and patterns we have identified to a more collaborative focus and process support with mobile AR. Positive experiences have been made in our first formative evaluations and we are working on a new prototype supporting a mobile audio augmented reality for a more immersive experience, easy annotation recording, and sharing in mobile learning.

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