Hand-held Mobile Augmented Reality for Collaborative Problem Solving: A Case Study with Sorting

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Abstract

Due to the advances in mobile technology, mobile augmented reality has been widely used for many disciplines. The ubiquity nature of mobile augmented reality supports a flexible, engaging and entertaining learning environment. However, most mobile devices are hand-held, and they require multitasking (mobile information processing and learning) that is a major hurdle for learning. This paper investigates the effects of multitasking of hand-held mobile augmented reality for problem solving. We design and implement a robust framework, and conduct a case study of sorting activities with two distinct groups: individual and collaborative pair settings. Experimental results demonstrate that 1) there is no significant difference between two groups in sorting without our proposed system; 2) there is a significant improvement with collaborative sorting with our proposed system. Test statistics confirm that our proposed system significantly improve collaborative pair sorting activities.

1. Introduction

Augmented Reality (AR) is an emerging technology that can be used to combine the physical world with virtual worlds through a visual interface. It augments the real world by superimposing virtual worlds to provide additional useful information. Thus the real world is enhanced by additional virtual content [27]. AR has been shown to be effective at accelerating comprehension and engagement with users of all ages in diverse disciplines [20]. Due to the advances in mobile and hand-held devices, AR is experiencing an explosion in popularity nowadays. The major benefit of hand-held mobile devices for AR is that the technology is ubiquitous and easily accessible to users. Hand-held mobile devices provide anytime and anywhere ubiquity and portability. It is predicted that mobile AR will reach $1.5 billion in global revenue by 2015 (http://www.juniperresearch.com/).

Mobile AR has been applied to numerous disciplines [3,20,27]. One of the most exciting areas is in education due to mobile AR's potential implications and numerous benefits for the augmentation of teaching and learning environments [2,3]. Research shows that mobile AR has potential to: enhance curiosity and motivation, boost collaboration, nurture imagination and creativity, create flexible teaching and learning environments, provide improved engagement, offer interactive context-sensitive learning feedback, offer location-aware information, and provide immersive learning experiences [6,9,15,16,20,23,27].

Despite the wide use of hand-held mobile AR for learning, the inability to use both hands for learning activities is a major hurdle. Mobile AR for learning is not hands-free, but it requires at least one hand to hold the device. It is still acceptable for learning tasks that do not require hands to do learning related activities but it is a clear disadvantage for some tasks that require hands to do some work. Some learning tasks require both hands to use to improve efficiency and effectiveness. In addition, mobile AR learning requires additional mobile information processing that is an added cognitive load. According to cognitive load theory [4], split-source information may generate a heavier cognitive load and decrease the effectiveness of learning. Thus, hand-held AR for learning is multitasking: mobile information processing and learning. However, multitasking is known to be an obstacle in learning since human context switching is expensive and multitasking causes more human errors due to insufficient attention.

Studies [7,10,19] show that humans have severe interference even with two simple tasks performed at the same time. [7] discusses cognitive distraction

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while multitasking with mobile devices. Therefore, how to overcome the multitasking nature of hand-held mobile AR for learning is of great importance. Most mobile AR learning studies focus on benefits and advantages [3,9,20,23,27]. To the best of our knowledge, no research investigates the multitasking nature of mobile AR for learning.

Sorting is an everyday activity that allows us to establish a sense of order in the surrounding environment. It is a fundamental math skill that is of extreme importance in many other activities such as in computer algorithms, database applications and especially for searching. It involves in re-ordering of objects by shape, letter or color either in an ascending order or in a descending order. Many sorting activities require hands to move objects around.

While sorting is not an explicit learning task, it has been shown that the relationship between task performance and technology is dependent on experiences with the technology and group membership, rather than on the type of task that is being completed [12]. Sorting is fundamentally a problem solving task, as it requires particular attention to the patterns and rules that are exhibited by a dataset in order to sort that data correctly. However, theories such as Bloom's cognitive taxonomy of learning can describe aspects of mobile-based sorting in terms of applying or using a procedure in a novel situation [26]. There are also aspects of sorting that fit into the psychomotor domain, for example sorting tasks require the ability to use sensory cues (e.g. shapes or numbers) to guide motor activity (physically moving objects into place). According to Simpson's extended taxonomy, this aspect of learning is called perception [24].

The main aim of this research is to investigate the effects of multitasking in mobile AR for problem solving through sorting tasks. This study develops a mobile AR application for sorting tasks and conducts a case study with two groups: individual sorting and collaborative sorting. The sorting task is manual and completed with the aide of hand-held devices to provide additional information. Experimental results show that 1) there is no significant difference between two groups in sorting without our proposed system; 2) there is a significant improvement with collaborative sorting with our proposed system. Test statistics (t-test and F-test) confirm that our proposed system significantly improve collaborative pair sorting activities.

The rest of this paper is organized as follows. Section 2 briefly reviews mobile AR learning. Section 3 introduces our proposed framework of mobile AR for sorting and explains details about major components of the framework. Section 4 presents various experimental results and discusses results in details. Section 5 concludes the paper and provides a list of future extensions.

2. AR for learning

AR refers to a live and real-world image enhanced by computer generated virtual contents. It is interactive, immersive and information sensitive [20]. It has been identified as one of top ten disruptive technologies for 2008 to 2012, and the advances in AR have been significant [20]. Benefits of AR can be further accelerated when it meets hand-held mobile devices. Mobile AR has been widely adopted in many disciplines in particular mobile AR wayfinding [5,18], and mobile AR for learning and teaching [3,13,22,27].

Mobile AR is expected to have a large impact on teaching and learning in university campuses and will be widely adopted in various educational settings [6,9,27]. It can help learners to experience imaginary worlds, to gain a deeper understanding, to dynamically interact with physical and virtual reality, to enhance their engagement and to boost creativity. Mobile AR for learning offers new opportunities for technology-driven learning, ubiquitous e-learning, situated and personalized learning, flexible learning, blended learning and practical learning [27]. Mobile AR has been used for learning difficult spatial, geometric and math concepts through dynamic 3D displays [1,11,14,25]. Mobile AR books based on 3D presentations have a great potential to provide learners with interactive 3D experiences [27]. Mobile AR gaming [13,22] is good to motivate and engage learners, and helps them easily grasp class concepts and learning outcomes. Mobile AR gaming presents educators with an opportunity to use entertainment based teaching [2]. Mobile AR for skill training is another area that highlights the benefit of mobile AR. This is especially useful in a dangerous, hazardous, expensive but a needed area such as military and mechanical examples [17].

It is well noted that the rapid development of technologies are dramatically changing the situation of both learning and teaching environments [27]. Educators are continuously required to develop new flexible and effective methods for learning and problem solving. Mobile AR provides a great potential to explore unexplored learning and teaching environments. Readers may refer to [6,8,9,22,25,27] for more details.

Despite the rich research in mobile AR learning, there has been no research in one of main issues of hand-held mobile AR learning: multitasking. This research investigates how this multitasking could be overcome by collaborative pair learning (students working in pairs to complete a problem solving task). In our experimental settings, collaborative efforts are more effective for sorting with our hand-held mobile AR system than personalized individual efforts, since the extra cognitive load caused by multitasking is now shared between the a pair of users.

3. Mobile AR for sorting framework

The proposed framework of mobile AR for sorting used in this study is shown in Figure 1. The framework consists of three main parts: input marker, mobile AR and algorithm, and the output of visual cues.

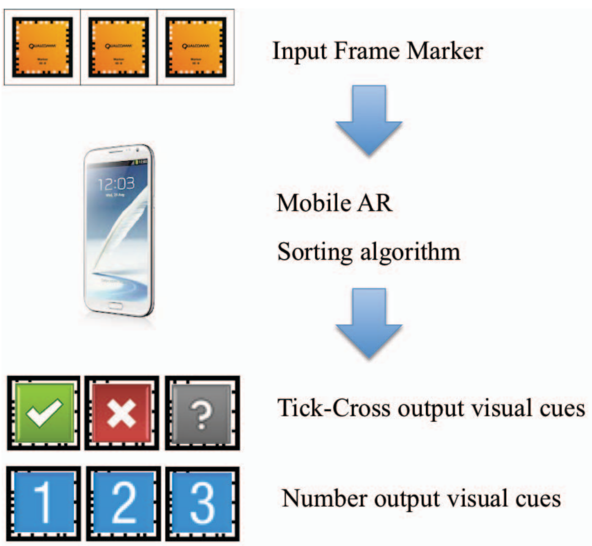


Figure 1: Proposed framework of mobile AR for sorting.

3.1. Input frame marker

Various tracking methods are used in mobile augmented reality applications including visual, non-visual and hybrid approaches. As tracking provides an AR-based application with the ability to determine the position of objects in the real world environment [28], it is important to select a method suitable to the application that is being developed. Visual markers are one of the most widely used tracking methods in existing AR systems [28]. Markers can be designed in many different shapes and sizes depending on the use of the application. However, squares are the most commonly used shape. This is because a camera calibration (pose and orientation) can be carried out with only a single square maker available as squares provide at least 4 co-planar corresponding points [28]. Due to this wide use of frame markers in AR applications, frame markers are used for tracking input in this study.

3.2. Mobile AR

The implementation of our AR system utilizes Vuforia. While there are several AR solutions available, we selected Vuforia due to its popularity and license-free nature which allows for simple development and distribution of applications (http://qualcomm.com/solutions/augmented-reality/). Further, as Vuforia is developed and distributed by Qualcomm, there are many industry examples of the software being utilized to solve real-world problems. The Vuforia SDK also provides support for iOS, Android, and Unity 3D. This means that applications can easily be extended to other platforms for wider usage.

The Android platform was selected for this prototype due to the open source nature of the platform and the widespread accessibility of Android devices for users. Instructions on the installation of the Vuforia SDK for Android is beyond the scope of this paper, however the process is explained in detail on the Vuforia website (https://ar.qualcomm.at/qdevnet/sdk/android). The Vuforia code is implemented using both the Android APIs and C++ (running through the Java Native Interface). The Vurofia SDK provides 512 unique markers that were used in this study.

3.3. Visual cues

Due to the limited screen space available on a mobile device, the visual cues provided by the AR system need to be straightforward and simple. For simplicity, a two-dimensional plane was modeled due to its robustness to changing textures and minimal use of memory. Four different textures were designed for the two-dimensional plane. Table 1 depicts the four types of textures and provides a justification for their use in the proposed framework.

The four textures are categorized into two modes: tick-cross output visual cues (tick, cross and question mark) and number output visual cues. The former provides an initial representation of input objects with qualitative positional information (tick for correct, cross for incorrect and question mark for unknown), whilst the latter represents quantitative positional information. These two modes can be toggled on and off by simply tapping on one of the textures.

Table 1: Textures used in this study.

Texture	Purpose
	The green tick texture is one of the tick-cross visual cues. It is used to represent an object that is in the correct order.
	The red cross texture is one of the tick-cross visual cues. It is used to represent an object that is not in the correct order.
	The gray question mark texture is one of the tick-cross visual cues. It is used to represent an object which the system is unsure about. This could be caused by a failure of the application to recognize the marker ID (defined in Section 3.4.). The colour gray was selected due to its neutral appearance. As all markers will begin with this texture (it may take a split second for recognition to occur), this marker should not be too distracting as to remove focus from more important markers.
	The blue number textures are used to provide visual cues for sorting. They represent the correct order of the currently visible objects. When a marker has been identified as being in the incorrect order (represented by the red cross), the system will provide instructions to the user so that objects can be sorted correctly. As there may be multiple markers that are incorrectly placed simultaneously, the system requires a method to show all errors in a non-confusing manner. Thus, all visible markers are given a number, indicating each object's correct position in an ascending order. As the numbers are only low (1 - 9), it is assumed that most users will have the ability to sort them quickly. The color blue was selected for this marker so as to stand out from the other colours (green, red, and grey).

3.4. Sorting algorithm

The sorting feature of the application is of importance for users. Vuforia does not provide a method for sorting markers, thus a sorting algorithm was designed and implemented for our study.

A challenge of implementing sorting with Vuforia is that it tracks markers in ascending order based on ID. Each marker is subtly different in appearance, and this difference corresponds to a unique ID number (from 0 to 511) that is retrieved by Vuforia upon tracking a marker with the camera. One technique that can be used to determine the order of the markers is to detect the horizontal coordinate of the marker as it is displayed on the two-dimensional interface of the device. The approach is illustrated in Figure 2. Assuming that the position of the camera always represents a fixed horizontal reference point 0, then a frame marker that is located directly in line with the camera will also have a horizontal position of 0. However, if a frame marker is positioned to the right of the camera position, it will have a positive horizontal coordinate (e.g. 10). Conversely, if a frame marker is positioned to the left of the camera, it will have a negative horizontal coordinate (e.g. -10).

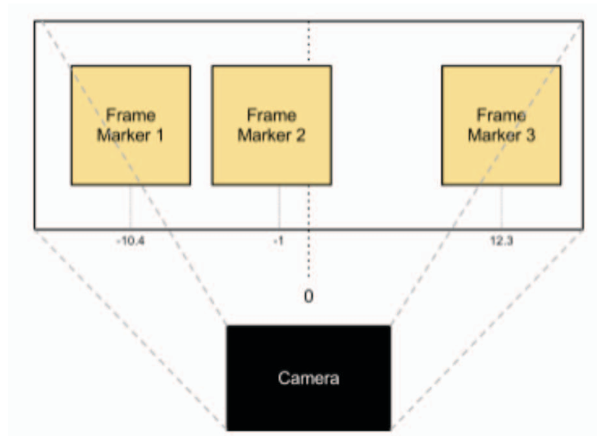
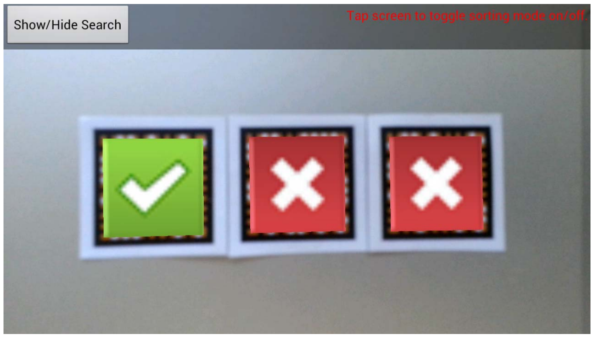


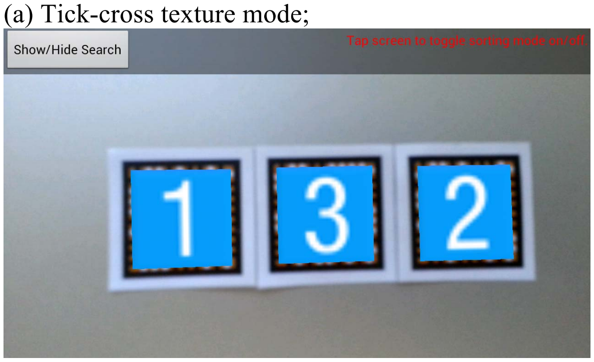
Figure 2: Detecting frame markers based on position relative to camera.

Our sorting method takes the marker ID and the corresponding horizontal coordinate for that marker when it is identified visually by the camera. The method then compares each horizontal coordinate with the next horizontal coordinate and reorganizes the list into an ascending order. Once the list has been sorted, a second function iterates through the marker ID numbers of the sorted map and assigns a correct texture (see Figure 3) for each marker according to its position. To conserve memory, the application only calls the sorting method if the visible markers have changed. This occurs if new markers become visible or if markers are moved to a different position in the real world. Additionally, memory is also conserved by dynamically updating the textures only when necessary.

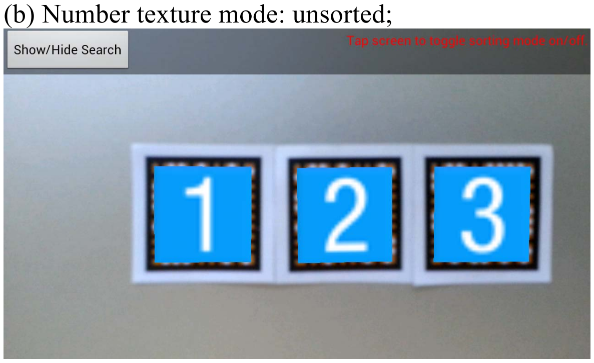
Figure 3 illustrates the implementation of the sorting process. Figure 3(a) displays initial tick-cross texture visual cues overlaid over frame markers. When a user taps the screen to toggle then numeric visual cues appear as shown in Figure 3(b). When the user swaps the second marker and third marker, then all three makers are in an ascending order as shown in Figure 3(c).



(a) Tick-cross texture mode;



(b) Number texture mode: unsorted;



(c) Number texture mode: sorted;

Figure 3: Screen captures of the sorting process.

4. Experimental studies

4.1. Hardware specification

Samsung Galaxy devices were selected for their larger screen size and memory capacity, which is beneficial in such a sorting task. However, our system can run on any Android mobile device. The Samsung mobile devices used in the study have Android 4.1.2 Jelly Bean operating system, 1GB RAM, camera with 5MP continuous auto focus and LED flash, and accelerometer, gyro, compass and proximity/light sensors.

4.2. Robustness of marker technology

There are a number of extraneous variables that may affect the performance of a mobile AR learning system. While marker technology is robust to certain visual noise and viewing techniques (i.e. distance and poor lighting), changes in the environment can result in false positives and negatives, which is an undesirable outcome for tasks like sorting. Therefore a preliminary study was conducted to determine the suitability of markers for sorting in various conditions. A brief summary of this experiment is as follows.

4.2.1. Distance. The distance at which a $150mm^2$ marker can be successfully tracked was found to be ~70cm. The continuous auto-focus functionality of the Samsung Galaxy device aided in this, as the phone was able to refocus itself so that it could track the marker at different distances. The distance varied slightly based on light quality.

4.2.2. Lighting conditions. It was found that the performance of Vuforia for tracking small frame markers was severely decreased when lighting was poor. In almost all instances, tracking performance was drastically increased by turning on the camera flash to provide artificial light.

4.2.3. Shakiness of device. While it was found that frame markers are robust to most extraneous factors, it does not handle slight camera shaking very well. As the application requires a user to hold the device with a certain amount of precision for individual sorting tasks, it is difficult to avoid minimal shaking of the device caused by the human body. This problem is further compounded in a poor lighting conditions or when there is some form of visual occlusion.

With these preliminary marker robustness experiments, it was concluded that experiments needed to be conducted in a carefully designed setting. In our experiments, participants are asked to sit on a chair in order to minimize shakiness, and use the device within ~50cm. Also, we ensure that maximum lighting is sought in the experiment.

4.3. A case study

A case study was conducted with 63 university students mostly in their last year of undergraduate studies (near graduation), and first year postgraduate studies (just graduated). All participants are currently studying an IT program at James Cook University, and randomization was used to control for differences in cognitive and learning skills. Participants were divided into two groups: an individual sorting group (21 students: 15 undergraduate and 6 postgraduate) and a collaborative sorting group (42 students: all undergraduate). The individual sorting group was disjoint from the collaborative sorting group. Note that both groups produced 21 sorting runs, since students in the collaborative sorting group worked in pairs.

The sorting task utilized a set of seven rectangular cards, printed with both a frame marker and a Dewey Decimal call number (e.g. 005.14 CAR). These cards were placed side-by-side on a table, imitating the layout of book spines on a library shelf. Participants were randomly allocated into individual or collaborative conditions, and both groups completed two sorting tasks, one with and one without the assistance of our mobile application. For each condition, the markers were shuffled into a random order, and participants swapped the position of markers by physically moving the rectangular cards. In the mobile sorting task, participants were provided with additional sorting instructions on the mobile screen. In the non-mobile sorting task, participants were expected to sort the cards using only the Dewey call numbers.

(a) Individual sorting; (b) Collaborative sorting;
Figure 4: Participants conducting the sorting task.

In the individual sorting group, each student is supposed to do multitasking (mobile information processing and sorting physical markers) whilst in the collaborative sorting group each pair is assumed to do a single task each (one student interpreting the mobile information and another student sorting the physical markers). In the collaborative sorting task, students were allowed to communicate to collaboratively solve the sorting task. One student holding the device plays a coordinator role whilst the other student sitting on chair plays a performer role. The coordinator role participant is expected to provide controlling information to the performer participant including sorting feedback and information. Figure 4 illustrates participants conducing the sorting task.

The library is one of the places in the university that requires a lot of sorting. Books are constantly being moved, loaned, and misplaced. They need to be sorted to be in the right place for users to find books they want. The Dewey decimal classification is the most widely used library sorting system to organize books so that books that are on the same subject are close and near each other. Dewey decimal numbers and alphabet letters are not straightforward for students to sort, but not extremely hard. For these reasons, the frame markers with Dewey numbers were used as sorting objects in this study. In our study, 7 markers were used for test.

4.4. Experimental results

Figures 5 and 6 illustrate rudimentary comparison plots of the individual sorting group and the collaborative sorting group respectively. Both plots are ordered (ascending) by the time taken to sort without using the app. Table 2 lists the mean times for the sorting tasks for each group with and without the app.

This data show that the sorting time is clearly faster for the collaborative sorting group using the app. This implies that cognitive load must reduce for each student in the collaborative sorting group (without disturbing multitasking), allowing them to focus on a single behavior during the sorting task.

We categorize the observed behaviors of the students as follows: 1) an individual student focuses on the app for guidance for what changes to make; 2) an individual student relies on their common-sense without the app; 3) a collaborative student uses the app to ask the other student in the pair to move the markers; and 4) a collaborative student asks the other student in the pair a question regarding the markers (regardless if they held the mobile device or not).

Students in the individual sorting group seemed to use the app without relying on their own skills to perform the sorting task. That is, it was observed that the participants' focused attention on the mobile screen and viewed their actions through the camera while manipulating the cards. This implies that the students blindly trusted the correctness of the app. Figure 5 shows that this caused problems when the app failed to work correctly, which happens when markers fail to register correctly. We suggest that some sort of quality metric could improve this result.

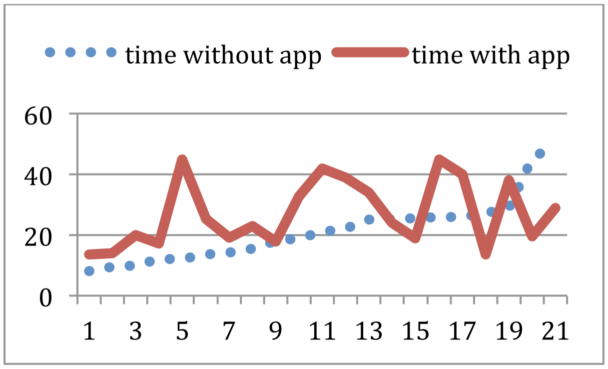


Figure 5: Individual sorting group (x-axis: participant, y-axis: time in seconds).

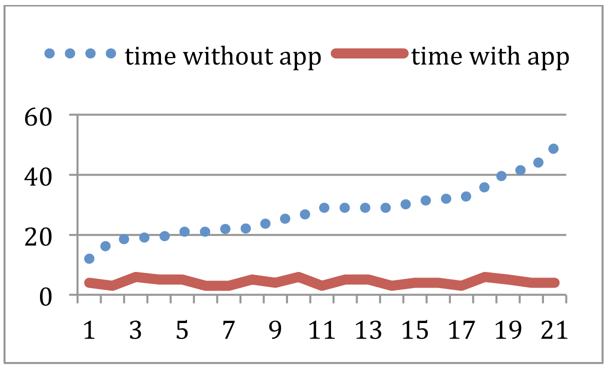


Figure 6: Collaborative sorting group (x-axis: the number of pairs, y-axis: time in seconds).

Students in the collaborative sorting group that used the app appeared to have static roles, one student focused on moving the markers and the other student focused on using the app. This plausibly contributed to the quick sorting times. But, when the collaborative sorting group worked without the app, they appeared to switch dynamically between roles and it takes time to communicate suggestions between the pair.

Table 2: Means and standard deviations of the sorting task.

Group	Task	Mean (sec)	StDev (sec)
Individual sorting	without app	21.62	10.84
	with app	27.18	10.87
Collaborative sorting	without app	27.81	4.29
	with app	8.99	1.06

Table 3 presents the results of paired-sample *t*-tests for the interesting comparisons between sorting groups and app usage. The app did not significantly change the performance of an individual student. This implies that focusing on the visual cues provided by the app for guidance or just relying on Dewey classification numbers had no effect on overall performance in this scenario. This seems plausible since an individual must be continually switching between using the app and moving the markers. The positive effect of using the app is negated by the negative effect of multitasking between behaviors.

Table 3: Significant *t*-test (df:20, p=0.1:1.72, p=0.05:2.09, p=0.01=2.85).

Task	*t*-test statistic
Individual without app & Individual with app	1.66
Collaborative without app & Collaborative with app	11.91
Individual without app & Collaborative without app	2.01
Individual with app & Collaborative with app	9.61
Individual with app & Collaborative without app	0.20

Notice that no significant difference occurred between individuals who did not use the app and those collaborative pairs not using the app. The probability of t = 2.01 arising by chance is less than p = 0.05, thus it is not significant with 95% confidence. Two important findings are: collaborative sorting with and without app, and individual and collaborative with and without app. The former *t*-test statistic 11.91 and the latter *t*-test statistic 9.61 are much greater than p = 0.01 (2.85), thus it is significant with 99% confidence. This means that there is a significant improvement with our app for collaborative sorting.

Table 4 shows the results of checking for equality of variance, which corroborates the significances of the *t*-tests for these comparisons. One notable finding is that the difference between collaborative sorting with and without app is significant. The *F*-test static for collaborative sorting with and without app is 3.60 that is greater than α=0.01 (2.94) which confirms it is significant with 99% confidence. These statistical validations verifies the importance of hand-free nature of sorting task, and also confirms that our proposed mobile AR learning system significantly improves the performance of collaborative pair sorting.

Table 4: Significant *F*-test
(df:20, α=0.1:1.79, α=0.05:2.12, α=0.01=2.94).

Task	*F*-test statistic
Individual without app & Individual with app	0.99
Collaborative without app & Collaborative with app	3.60
Individual without app & Collaborative without app	0.41
Individual with app & Collaborative with app	0.38
Individual with app & Collaborative without app	0.40

5. Final remarks

In this paper we investigated the effects of multitasking on hand-held mobile augmented reality for problem solving. It is clear that collaborative sorting tasks are performed more efficiently due to the sharing of tasks between group members (e.g. one member holds the device and interprets the mobile information while the other can use two hands for sorting) and communication. In contrast, there were no significant improvements for individuals learning the sorting task, indicating that AR provided no immediate benefits. Further experiments with a variety of complexity of tasks are required for the validation of the proposed system for diverse learning tasks.

It is also predicted that AR will play a dominant role in future education [8], however there is a clear need for improvements. With the advent of new technologies and advances in information technology, new methods of teaching will be developed [8]. There is currently a trend moving towards wearable technology (thus becoming hands-free), with projects such as Google's Project Glass (http://www.google.com/glass/start/) and Meta 1 (http://www.meta-view.com/) paving the way for hands-free AR interfaces with gesture-based input. The introduction of hands-free AR devices will have several implications for education, as there are learning benefits specific to hands-on tasks [21].

While there are important benefits for students to be gained from collaborative learning, it is also important for students to develop individual problem solving skills. By overcoming the current hurdles of mobile AR-based learning (e.g. holding a device while interacting with the real world), it is expected that cognitive errors will be reduced and learning efficiency will be increased overall. Thus, it is recommended that future research in this field should investigate the effectiveness of hands-free, AR devices at reducing cognitive distraction. Additional methods for displaying mobile information should also be investigated as to reduce the cognitive load on a user who is also completing a secondary task. It is expected that the next generation of mobile devices will reduce the need for multitasking in mobile AR, as users will have both hands free to interact with objects in the surrounding environment.

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