Through the Looking Glass: Visualising Design Details with Augmented Reality (AR)

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CONTEXT

A consequence of the rapid growth of computation power and ubiquity of consumer mobile devices has been that the use of augmented reality (AR) application as educational tools to enhance the learning experience of students has become feasible (Henrysson, 2007) (Nesloney, 2013). In addition, with increasing number of students, the availability and storage space for physical equipment in hands-on laboratory sessions can be an issue for teaching delivery. We have developed an augmented reality application that can be used on student mobile devices to aid in the teaching of Geometric, Dimensioning and Tolerancing (GD&T) in a laboratory session of a Mechanical Engineering Unit. The application package was developed to help students to bridge the gap between the theoretical understanding of GD&T and how it is applied in the manufacturing design process in the industry.

PURPOSE

The objective of this research is to evaluate the efficacy of an augmented reality application designed to create an active learning experience and demonstrate the significance of GD&T.

APPROACH

A specific GD&T laboratory session will include an additional task utilising the augmented reality application. Feedback from students that participate in the new laboratory session will be recorded and evaluated to determine the impact of augmented reality in connecting their experience with the pre-class learning materials and the learning outcomes. Results will be compared with past student cohort feedback on the non-augmented laboratory session.

RESULTS

The majority students perceived that the additionally included exercise, incorporating the AR application was beneficial in reinforcing their knowledge on geometric tolerances.

CONCLUSIONS

The research study demonstrated the effectiveness of AR as an additional learning tool in providing students the opportunity to develop better understanding and visualisation with a hands-on experience in real-time. Indeed, students find this comparatively more engaging than the conventional teaching methods that involve the measurement of different dimensions of various mechanical parts to quantify manufacturing imperfections.

KEYWORDS

augmented reality, geometric dimensioning and tolerancing, tolerance, metrology

Introduction

The undergraduate Mechanical Engineering unit, MEC3416 Engineering Design II at the University of Monash is designed to introduce students to the design of machine elements, covering the aspects for bearings, shafts, gears, etc. Ultimately, upon successful completion of the unit, students are expected to have a comprehensive understanding on geometric and economic tolerancing as well as to examine the techniques for improving engineering designs based on economic and functional requirements. During the course of the unit, students will be required to participate in a metrology laboratory closing the end of the semester. The briefing sessions and series of online video presentations were given to the students prior to the laboratory session. All things considered, the overall learning outcomes that were designed into the laboratory revolves around the following elements:

1. Describe the role of measurement in the manufacturing design process
2. Measure dimensions of parts to verify manufacturing output on a component level
3. Specify the geometric tolerances required for a functional design

In the laboratory, students are presented with different components, detail drawings with specifications, the metrology tools and corresponding metrology report. The tasks allocated to the students was to first analyse and study the drawings and through observation of the parts, then infer possible functions of the assembly and relationship between the components. Subsequently, with the use of the tools (Vernier caliper, micrometer, etc.) provided, students are to measure the parts and document the measurements in the metrology report template. Thereafter, the students were instructed to determine the passing and failing criteria for the parts with the average readings obtained. At the same time, from the data collected, students then analyse and make the deduction on whether the intended functional operation of the component has met the specifications or else fail. In addition, the students were then expected to reflect and comment on the different parts, this time keeping in mind the passing and failing criteria that was drawn out from the observations earlier.

As an additional component or element for the laboratory, a different approach of incorporating an augmented reality application as an additional learning tool was considered. This added aspect was explored as a consequence of new advances in augmented reality content creation as well as the ubiquity of student mobile devices, in which using such application to enhance the learning experience of students has become greatly possible and achievable. Interestingly, most augmented reality application being developed are compatible to increasing number of mobile devices due to the rapid growth in computational power and the significant decrease in power consumption (Henrysson, 2007). Taking advantage of these, augmented reality can be introduced to the students and even be used on their mobile devices to aid in the teaching of a particular material content. On top of that, the idea of the inclusion of augmented reality in learning space can also resolve the issues of having limited availability and storage capacity for equipment in hands-on laboratory experiments too.

Augmented reality (AR)

Augmented reality (AR) is a mixture of a direct and indirect view of the physical, real-world environment, a technology that superimposes computer-generated elements over a user's view of the environment, which can be as simple as through a display of a camera. It is a space; a vision where digital domains can be blended with the impression of the physical world. Augmented reality enhances individual's perception of reality, whilst virtual reality replaces the entire real world with a simulated virtual environment (Henrysson, 2007). Thus, augmented reality creates a composite mixture of reality. This can be best described with the Milgram's Reality-Virtuality Continuum as shown below.

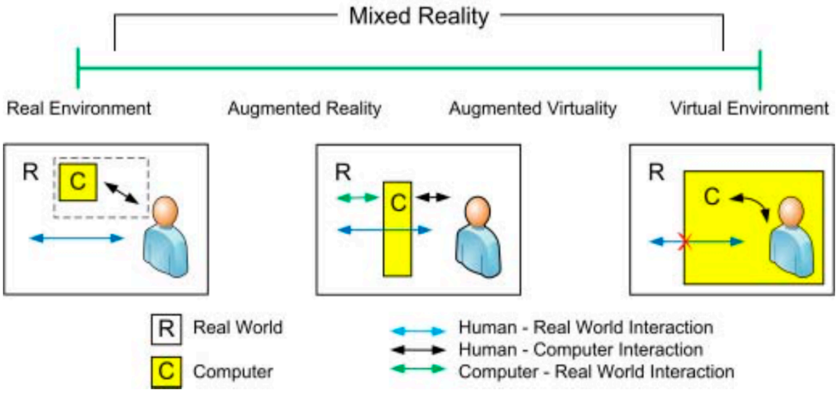

Figure 1: Milgram's Reality-Virtuality Continuum (Henrysson, 2007)

The continuum spans from real-world environment to virtual environment at both extreme ends, where in between lies the mixture of reality. With reference to the figure above, augmented reality superimposes both the domains of human-real world interaction and computer-real world interaction, where this eliminates the need for switching of focus between domains (Henrysson, 2007). As augmented reality has the characteristics of combining both real and virtual elements, information such as the surrounding environment of the users can become more interactive and manipulable in real-time.

Motivation

Having learners diving into the augmented space where they can have two-way interactions with virtual objects in the digital domain and the physical real-world environment, is rising as one of the prominent approaches in creating unique educational settings. The means of incorporating augmented reality as part of a teaching and learning tool has created much interest in the education field with the intention to enhance and redefine learning experience of the learners (Kesim & Ozarslan, 2012) (Wang, 2012). It is also said that augmented reality is aligned with the constructivist notions of education, in which promotes self-directed learning through interactions with the real and virtual environment (Wang, 2012).

In fact, the augmented reality application in this context will be focusing on how AR as an additional learning tool can be a supplement to the learnings of the students, rather than replacing the conventional method of implementing two-dimensional medium in education.

The potential of augmented reality in education is also justified with the ability to provide an adequate level of realism, in which individuals are not disconnected entirely from the real environment (Kesim & Ozarslan, 2012). To emphasise on the statement above, augmented reality can be adopted as an additional learning platform for students to visualise things as part of the learning process more effectively, leading to the creation of a more intuitive learning experience which can boost their level of understanding. A structured interaction with the moderate dynamic representation of information is known to be able to improve learning significantly as articulated in research conducted in the past (Bodemer, Ploetzner, Feuerlein & Spada, 2004).

This study analyses whether the nature of augmented reality is capable of complementing the overall learning experience of the students in terms of better visualisation, and provide a context for incorporating augmented reality application in the curriculum of studies.

Methodology

To analyse the effectiveness of augmented reality in enhancing the learning experience by creating a mixed reality environment where users can interact and manipulate the surrounding superimposed elements, an augmented reality application prototype was developed. The application package developed was with the intention of providing a platform for students to visualise how different tolerances could place an effect on the manufacturing output on a component level and the subsequent functional operation of a part. Therefore, the primary motive is to complement the existing metrology laboratory in reinforcing the understanding of Geometric, Dimensioning, and Tolerancing.

Software Development Tools

A list of tools and platforms used to develop the augmented reality application are provided below, followed by a brief description of each.

1. Vuforia Augmented Reality Software Development Kit (SDK)
2. Unity3D Game Engine
3. MonoDevelop (Xamarin Studio)
4. Blender

Vuforia is a fundamental software element that was used to enable the building block of the augmented reality application. This software is utilised to provide tracking and recognition capabilities on different pre-defined targets by employing computer vision technology. In the case of the developed application, a planar image tracking along with the 3D object (point-cloud based) tracking were implemented to superimpose virtual components on the physical world environment in real-time.

Unity3D is a game engine that was used for the functions to create, edit and integrate data and code onto the recognised target markers in the real-world space. Unity allows the overlaying of different digitalised components with relative to the target in the physical environment. The tools offered by the software package such as the user interface blocks were also exploited to create a more intuitive and interactive application, where users will be able to manipulate the augmented objects in real-world space.

MonoDevelop which is an inbuilt application of Unity, which is an open source integrated development environment, which enables advanced C# scripting for more complex high-level applications. It was used to compile cross-platform application by the compiler of Unity. Fundamentally, MonoDevelop was used extensively to provide corresponding interactions and feedbacks between the user and the augmented components in the scene.

Blender is an open-source 3D computer graphics software, which was used to create and render objects and components with higher complexity in shapes to create a more realistic 3D augmented reality application. For instance, 3D modeling, texturing and more features were used in creating the different assembly parts to be generated for the application.

The above tools and platforms were chosen in developing the augmented reality application is because they have the common features in offering a cross-platform development engine, where the built application package is compatible with many different devices and operating system. Essentially, the software packages are also free for development purposes with a wide range of inbuilt functionalities and application program interfaces (APIs). Not to mention, they also provide great documentation and community to aid new developers.

Approach

A total of four students who previously participated in the laboratory session were invited to participate in a survey evaluation and application usability test to evaluate the augmented reality application that was designed to enhance the learning of the concepts in Geometric, Dimensioning and Tolerancing. The survey was intentionally simple, designed to investigate if the perceptions and understanding of tolerances on the manufactured output were amplified with the additional element of having augmented reality as part of their activity. The primary questions asked and focused in the survey questionnaire was whether the students understand the following aspects before and after the exercise:

1. The context of tolerance in parts manufacturing perspective
2. Effects of tolerance on the operational function of the product

These were both evaluated first at the pre-activity of the session and towards the end of the activity to review the effectiveness of augmented reality in bridging the gap between theoretical and practical understanding through constructive visualisation of the material presented. Moreover, a background video of the testing was also recorded for usability testing to evaluate the AR application developed, thus, provides a direct input on the tool's capacity to meet its intended purpose.

In essence, the activity for the survey evaluation for the augmented reality application was carried out at 3 different stages, comprising of understanding assembly drawings, generating the augmented part with different tolerance set, and finally analysing the functional operation of the assembly with the augmented part interfaced with the physical 3D-printed base.

The participating students were first briefed with instructions for the testing at the start of the session, which was then followed with a pre-activity questionnaire. A 3D-printed base with feature markers was then provided to the students with the assembly drawing, along with the specification of the clamp to be generated in the augmented space. Each student was also provided with a tablet with the developed application package installed beforehand. Consequently, the overall setup of the testing includes an Android device, assembly drawings for both 3D-printed base and the clamp to be generated, a target marker for the overlaying and positioning of augmented clamp generated, as well as the 3D-printed base with feature markers attached shown as followed.

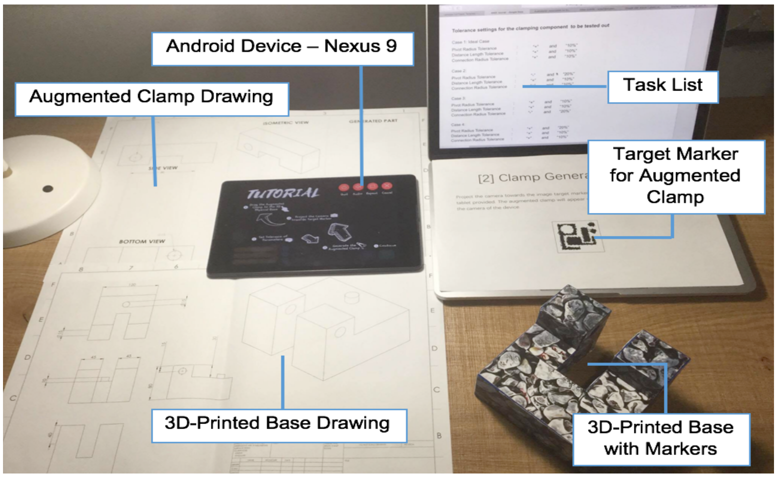

Figure 2: Application testing activity setup

Each student was then given 15 minutes to complete a series of tasks with the augmented application to examine their level of understanding on the effects of geometric tolerance. As a result, their level of understanding can be reflected through their deduction and explanation made on the end functional operation of the assembly.

The procedure of the application testing is summarised in the flowchart as shown below in Figure 5. Stage 1 of the activity involves the student analysing the assembly drawings and understanding the intended functional operation of the end assembly to be constructed. For instance, this includes the required clearance fit for the generated clamp to be interfaced with the physical 3D-printed base and their corresponding functional expectations.

Moving on, students were recommended to follow the tutorial instructions that were embedded in the application for the following stages. In the following stage 2 and 3, students were required to evaluate the effects six different unique cases of tolerance settings (extreme cases), where the corresponding output obtained was studied. The set of tolerance settings for the analysis was provided and upon inputting the tolerance, students can then generate the augmented clamp on the target marker in the scene with respect to the corresponding set parameters. Students then able to look at a different view of angle of the generated augmented clamp in the scene by projecting the tablet’s camera onto the image-based tracking marker. Once students are satisfied with the part generated, they can then interface both the augmented clamp and the 3D-printed base together in the real-world space by dragging the corresponding part to the physical base provided. At the instance when both the augmented component in the digital domain and the physical base in real-world space collide, the clamp would then be clicked onto the base, creating an assembly as shown in Figure 3.

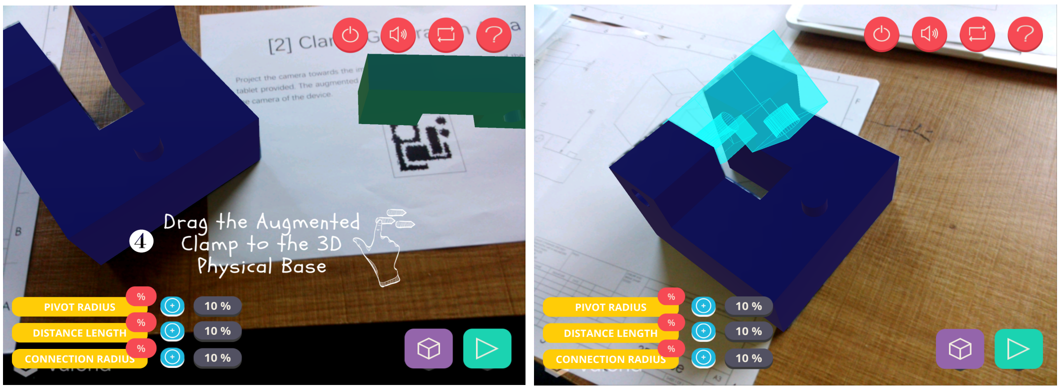

Figure 3: Generated augmented clamp and interfaced assembly

The interfaced clamp would then change from a solid texture colour to wireframe to provide better visual views of the clamp.

In stage 3 of the exercise, students were directed to the next scene where the interactions of users and the augmented elements come into place. Likewise, the students can then interact with the augmented clamp generated and manipulate them with the user interface that was designed. For example, this includes rotating the clamp around the pivot of the physical base to translating the parts if the connection was loose. Through the observations and interactions, students are then required to examine the effects of the tolerance set previously in generating the clamp on the relative clamping mechanism.

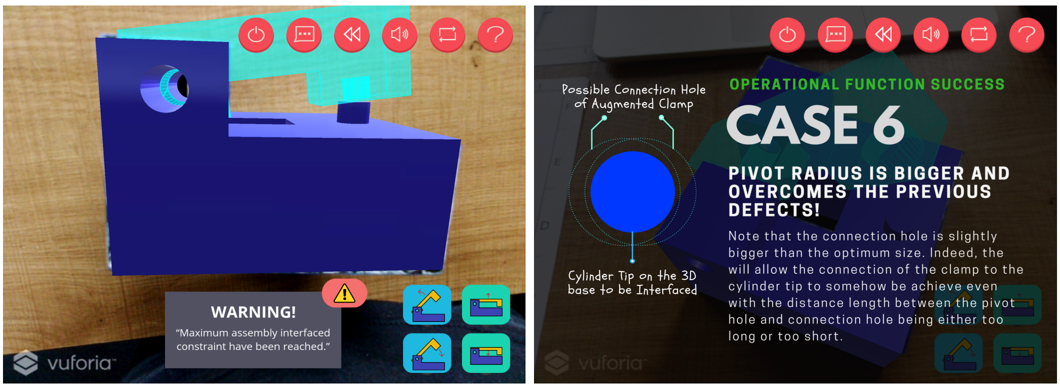

Figure 4: Built-in interaction feedbacks and analysis to aid learning

More interestingly, with augmented reality, students can instantly observe the assembled part at different angles. Furthermore, feedbacks were also received based on their interaction with the assembly, which can be in the form of vibrations when the part’s movement reaches the boundary limit of the interface to distinctive alert messages to aid in their understanding as illustrated in Figure 4. For all intents and purposes, the students are expected to be able to verify their understanding of the effects of tolerance setting that was allocated for the clamp generated towards the functional operation of the end assembly. The steps discussed above are then repeated to explore the other possible cases and then concluded with the post-activity survey questionnaire. A short interview was also conducted with the participants to get some valuable feedback on the features they find helpful and elements to be improved or amended to further revise the application package developed.

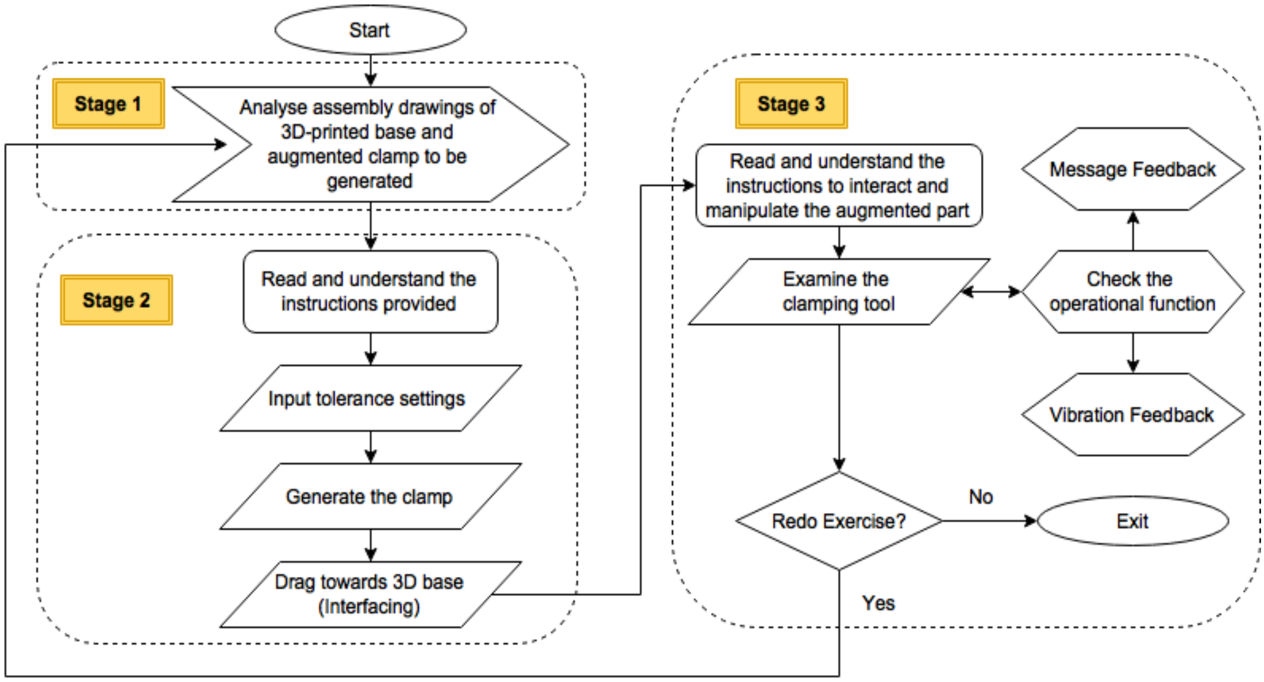

Figure 5: Overall application testing flow

Results

Understanding of tolerance

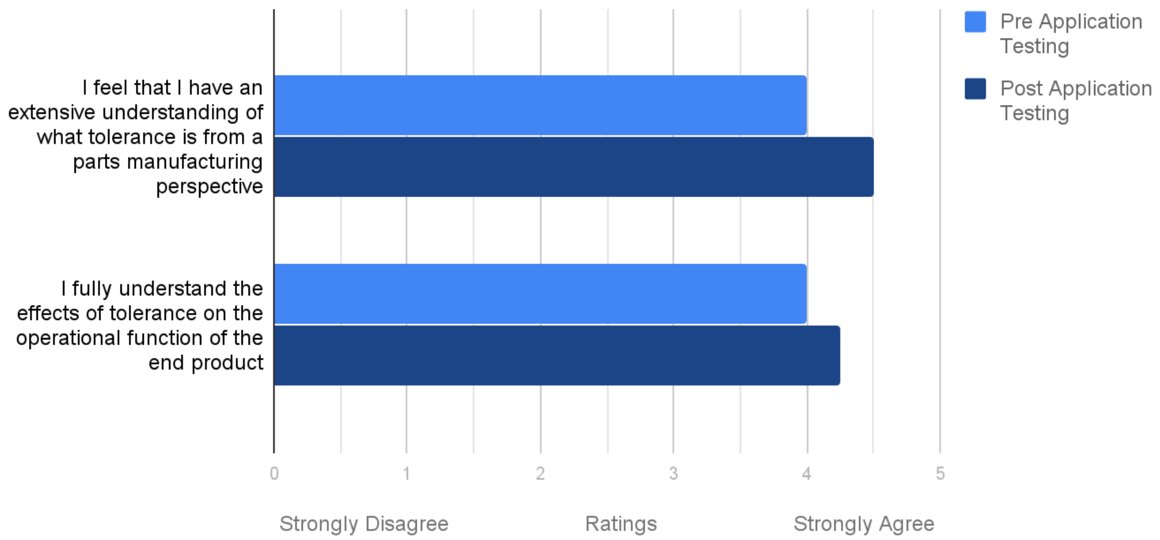

Figure 6: Relative feedback on the understanding of tolerance

The relative feedbacks of the initial part of the survey is then tabulated as shown in the Figure 6 above. Overall, the students who participated in the survey evaluation could develop a better understanding on what tolerance is from a part manufacturing perspective after using the augmented reality application package, where there is an increase of the average rating of 0.5 from 4.0. On the other hand, students find themselves having a greater viewpoint and perspective on the effects of difference set of tolerance for the generated part towards the operational function of the end assembly after the corresponding interfacing was carried out. As a result, there was a slight increase in the overall ratings, which reflects that there is a considerably good amount of added value to the learning experience of an individual with the use of external learning tools such as augmented reality.

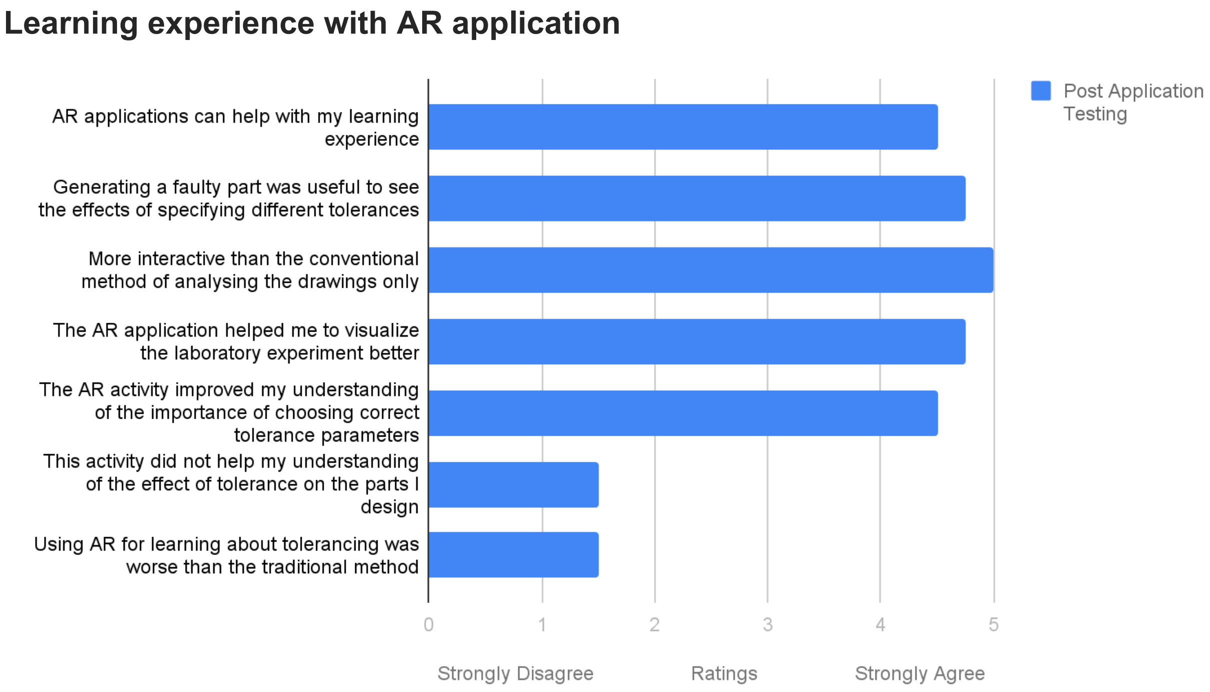

Figure 7: Feedback on the learning experience

On average, participating students believed and acknowledged that the additional assistance of having the developed augmented reality application creates a more intuitive environment for better learning experience. Indeed, the result turned out to be at the best rating possible of 5.0, where students strongly agree that this approach of learning was more interactive than the conventional method of just analysing the assembly drawings. Figure 7 also shows the use of additional tools such as augmented reality can promote better visualisation of the laboratory experiment, especially with the ability to generate a faulty part on the instance and observe the subsequent effects on the assembly. Majority of participating students also considered that the AR activity has improved their understanding of the importance of choosing the correct tolerance parameters, to produce parts that are within the usability criteria. There was also a positive outcome from the data collected, in which past students disagreed with the statement that the additional augmented reality application prepared for the activity didn’t help them in learning more effectively with a rating of 1.5.

User experience with the AR application

Further analysis showed that students have a constructive and interactive experience in using the augmented reality application during the activity with a total average rating of 5.0 as illustrated in Figure 8. Some students participated in the activity found it slightly complicated to get started, however, most of them got used to it over time. In brief, students find that the additional activity of having augmented reality incorporated into the laboratory would have been helpful for them when undertaking the laboratory session in the past.

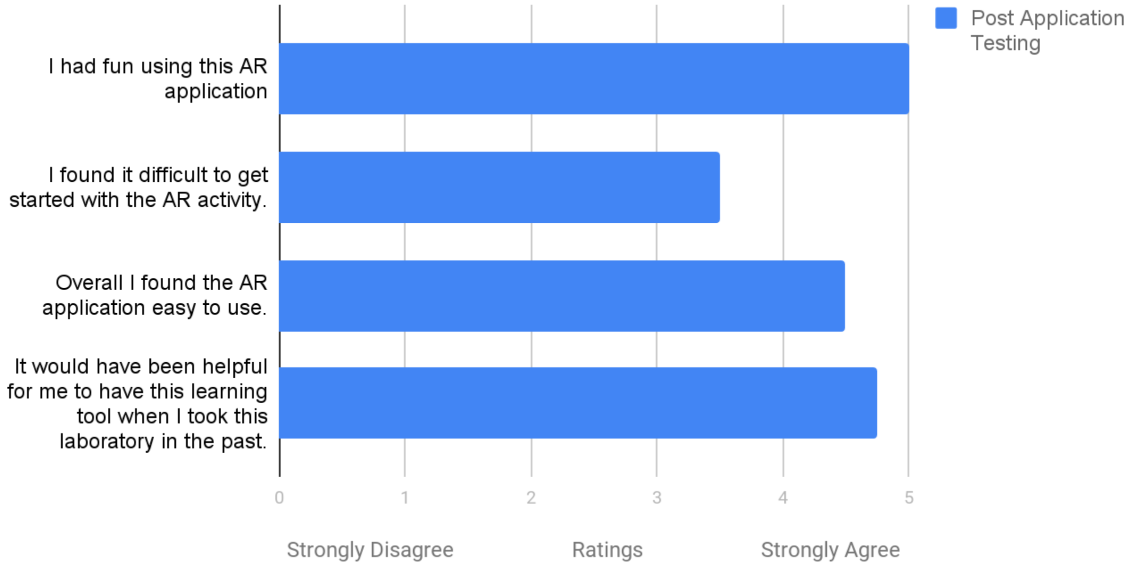

Figure 8: Feedback on user experience

Usability Test

From Figure 9, a positive correlation can be observed between the transition of each cases that was carried out by the students, where the time taken for students to complete a set of task is reducing as they get used to the augmented reality application. This clearly indicates and justifies the usability of the application developed as users were able to meet the expectations at the given timeframe. As for the scenario where students encounter any difficulties or experience any form of confusion, the longest time taken to overcome the issue was below a minute. Hence, the application is usable and intuitive to some extent as there were minimal issues that were experienced by the users.

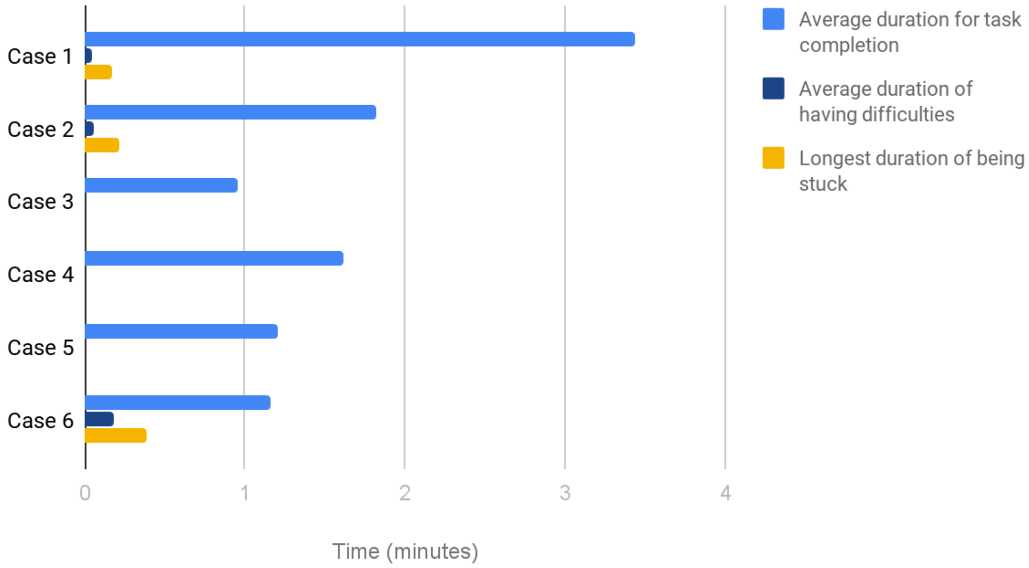

Figure 9: Data collected from recording for usability test

Discussion

As all students participated in the survey evaluation activity completed the tasks allocated with the allocated time, our results obtained met the expectation in students improving the understanding of Geometric, Dimensioning and Tolerancing concept. Also, the augmented application was observed to have created a more interactive and engaging learning experience, as students were interacting with the digitalised virtual object and the physical base at the different point of views. The fact that students were able to make the correct deductions on the effects of the tolerance set on the end functional operation of the assembly strongly linked to totality that augmented reality can provide in the learning phases.

Other comments worth noting from the students were that having the additional element of augmented application would be a really useful tool to help them understand any topics being taught in a more captivating approach. Besides, from the feedbacks collected, students find this method of learning fun and efficient in terms of quality and speed of teaching. The students participated in the activity also appreciates the value of augmented reality in having the ability to provide them different dimensional viewpoints of a piece of information for better visualisation.

On the other hand, a selection of students found the tutorial instructions incorporated into the application interface slightly confusing at the start, but the overall feedback was easy to use after they get used to the functions. At times, some students couldn't see the parts clearly due to the factor that the colour combination of augmented part and the physical object after the overlaying was not clearly distinguishable. Another constructive feedback was that the dragging and dropping of the generated part onto the base model in the real-world space was a bit glitchy and maybe unnecessary as well.

Next, from the usability test conducted simultaneously, some potential issues were highlighted such as the developed augmented reality application can be glitchy at times, in which the camera lose track of the augmented part before the interfacing phase. Despite that, the application was able to be reset with the user interface button embedded and was fully functional after that. It may be due to the factor of bad lighting in the testing room, where a marker of bigger size and a comparable larger number of feature points on target markers could potentially fix the glitches. Nonetheless, the application developed as a whole in terms of its likelihood of usage and repeatability was satisfactory.

Additionally, as for the future work on the augmented reality application, would be to explore more into its capabilities and potential in the creation of a more interactive learning environment. Similarly, a more compact and simple tutorial instruction would be integrated into the application without compromising the relevant details, to heighten the level of interaction between the user and the digitalised components.

Conclusion

While the AR application is designed to help investigate the effectiveness of the additional tool in providing an interactive learning experience, the exercise conducted showed great potential and viability of augmented reality in the education sector. Results of the activity carried out also indicate that augmented reality as a supplementary tool can be highly effective in providing learners a platform for better visualisation in bridging the gap between the theoretical understanding of Geometric, Dimensioning and Tolerancing and the practical application and effects in the manufacturing design process.

Augmented reality is a tool where students can test and examine their level of understanding by applying the appropriate interaction to the superimposed digitalised component in real-time. The feedback in terms of visual can be provided at the instance, which is supported by the fact that there is no cost involved in making mistakes and errors. Thus, it creates opportunities for more practical and diverse learning. With AR, the definition and scope of learning experience can be expanded and redefined into a whole new level.

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