DISCOVERIES FROM STUDENTS' INTERACTIONS WITH AN IMMERSIVE LEARNING APPLICATION.

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ABSTRACT

Immersive learning applications in chemical and process engineering are creating the opportunity to bring the complexity of entire process plants to the student. While meant to complement field trips, in some cases, this is the only opportunity for students to engage with certain industrial sites due to site regulations (health and safety, hygiene, intellectual property, etc.). An immersive learning application, representing a milk powder process plant, is used to test the students' affinity to these types of learning supplements. Further the students' learning outcomes are investigated and are compared to traditional course material.

The application tightly integrates a number of different "views" of the process plant, such as panorama photographs, process flow diagrams, piping and instrumentation diagrams and 3D plant maps. The individual "views" are connected via a text module which allows the identification of equipment and enables the user to gain a deeper understanding of the process.

This paper compares the application's impact on learning outcomes to that of traditional course material in an introductory design course. We found that lower GPA students, studying the immersive learning application, scored significant higher marks than their counterparts, studying the traditional course material. For higher GPA students, no difference was observed. The learning style preferences of the individual students are also assessed and are utilised to rationalise the findings. Further survey results are included for a case study with a different group of students where the immersive learning application is used to create a virtual field trip in a classroom environment.

INTRODUCTION

The university environment is optimised for teaching fundamentals through lectures, lab classes and assignments but site visits and internships complement the class room environment to help put theory into context and improve students' understanding of complexity and scale. Field trips are thus a pivotal part in chemical engineering education.

With on-site access limited due to accessibility, safety issues and intellectual property concerns, it has become increasingly difficult for students to engage directly with industrial sites. Internships/summer work, by their nature, are unique to each student and therefore do not provide the collective breadth of the industrial environment during the students' academic training. A lack of industry exposure leads to deficiencies in the students' understanding of the design and operation of complex process systems.

This project addresses this deficiency by "bringing the plant to the learner", by means of a virtual reality immersive environment that generates deeper understanding and insight. While simple photographs cannot replace actual site visits, the integration of different representations of the plant (spherical photographs / 3-D drawings / process flow diagrams (PFDs) / piping and instrumentation diagrams (P&IDs), text) generates a powerful learning tool for students (and operators), thereby supporting learning in traditional course work areas like design, systems dynamics/control and risk management.

This paper introduces a new immersive learning application and compares its impact on learning outcomes to the traditional lecturing material. The application is based on a milk powder production facility and has been substantially modified from its earlier draft version (Herritsch *et al.*, 2011).

THE IMMERSIVE LEARNING APPLICATION

A Fonterra milk powder production facility provides the content for the immersive learning application described in this paper. Fonterra is a New Zealand multinational dairy co-operative owned by almost 10,500 New Zealand farmers. Fonterra Co-operative Group Limited is New Zealand's largest company with an annual revenue of NZ$ 19.9 billion (Fonterra, 2011). In the production of skim milk powder, raw milk is pasteurised and the cream is removed. The remaining skim milk is concentrated in evaporators under vacuum at low temperatures (<70 °C). The concentrated milk is then atomised into hot air to further reduce the water content and form dry milk particles. Depending on the milk composition, about 10 kg of milk powder can be produced from 100 litres of milk. The specific facility described here is capable of producing 10,000 to 14,000 kg of milk powder per hour. Due to its large scale, stringent hygiene and safety conditions, compact nature, and the diversity of process units involved, this facility is an ideal candidate for an immersive virtual learning environment.

For this application, the development principles for educational multimedia are followed (Mayer, 2003 , Mayer & Moreno, 2002). These principles are derived from the cognitive load theory, which is based on the assumption that individuals possess a maximum processing capacity for information through learning channels. Exceeding the threshold capacity overloads the user, which in turn hinders the absorption of information. The main principles followed in the development are:

- *Multiple representation principle:* Explanation in the form of a combination of words and pictures are more effective than words or pictures alone.
- *Contiguity principle:* Simultaneous presentation of words and pictures works better than presentation in succession.
- *Spatial contiguity principle:* Closer proximities of text and image enhance the learning outcome.
- *Personalisation effect:* Deeper learning can be achieved by conversational style text rather than formal style text.

The immersive learning application tightly integrates a number of different "views" of the process plant. Over fifty 360° x 180° panorama photographs (nodes) document the process from the tanker reception to the packaging of the milk powder and are supplemented by text description of the relevant portion of the process. Detailed PFDs and P&IDs support the images and allow a deeper understanding of the process from an engineering perspective. Detailed 3-D technical drawings of the spray drier and the evaporators are used as "geographic" maps and create the links between the process engineering representations and the panorama photographs. These models also help students to gain a spatial awareness of the environment that otherwise may be limited due to the node-to-node navigation within the confined building. A model person is also added to the 3-D models to provide the students with the sense of scale of the actual unit operations in the building. The 3-D drawings include the main unit-operations and the piping for the main process streams, better linking the PFD and P&ID to the drawings.

The application framework hosts several inter-linked modules. Once the application is started, the "Home" screen is displayed where the student has access to background information and an introduction on how to navigate through the application. From the "Home" window, the user enters the main part of the application via a button click. The main part of the application is referred to as the plant virtual environment and contains the four labelled windows "Info Panel", "Pano Viewer", "Process Flow Diagram" and the "3D Map" (Fig. 1).

The "Info Panel" enables the student to follow a virtual tour through the milk powder plant from the tanker reception to packing. This tour contains eighteen of the most significant nodes. A node is a specific location in the plant which is photographed. The "Info Panel" contains basic information about the nodes, identifies areas of interest (hot spots) and provides a link to the appropriate P&ID. The photograph view is located in the top right panel. In the "Pano Viewer" window, the panorama photograph can be rotated and zoomed in/out via a mouse or a touchpad. In addition, the size of the panel can be increased to enlarge the photograph. The bottom left panel contains PFDs of the process. Depending on the current position within the virtual tour, the bottom right panel contains either a 3-D model of the entire plant, the evaporator or the spray drier. Green highlighted camera symbols are displayed on the PFD and 3-D model to indicate the position of the currently displayed photograph in the "Pano Viewer".

The student navigates through the tour by clicking the left (backwards) or right (forward) arrows, located in the "Info Panel", which updates the text, displays the new photograph and green high-lights the new camera symbols within the "Process Flow Diagram" and "3D-Map" windows. The user is able to leave the pre-defined tour and directly jump to the node of interest by clicking on the grey camera symbols in the PFD. Hovering the mouse cursor over a PFD camera symbol displays a tooltip and a grey camera symbol is shown in the "3D Map", indicating the physical location in the plant. This feature assists the user in selecting the next node of interest (Fig. 2). More screen space can be allocated to the "3D Map" window, allowing for a larger display of the 3-D drawing. In addition, the 3-D drawings can be rotated via a slider located below the drawing (Fig. 2). The student gains access to the P&ID either by clicking on the current P&ID button located in the "Info Panel" or by clicking on the P&ID button in the main panel. The second options starts the P&ID selector, which assists the students to choose the correct P&ID by displaying a detailed PFD containing active buttons linking to the corresponding P&IDs. The entire process is represented by 17 P&IDs and to reduce the complexity of an individual diagram, the user can enable or disable service lines such as CIP (clean-in-place), vacuum, air and water.

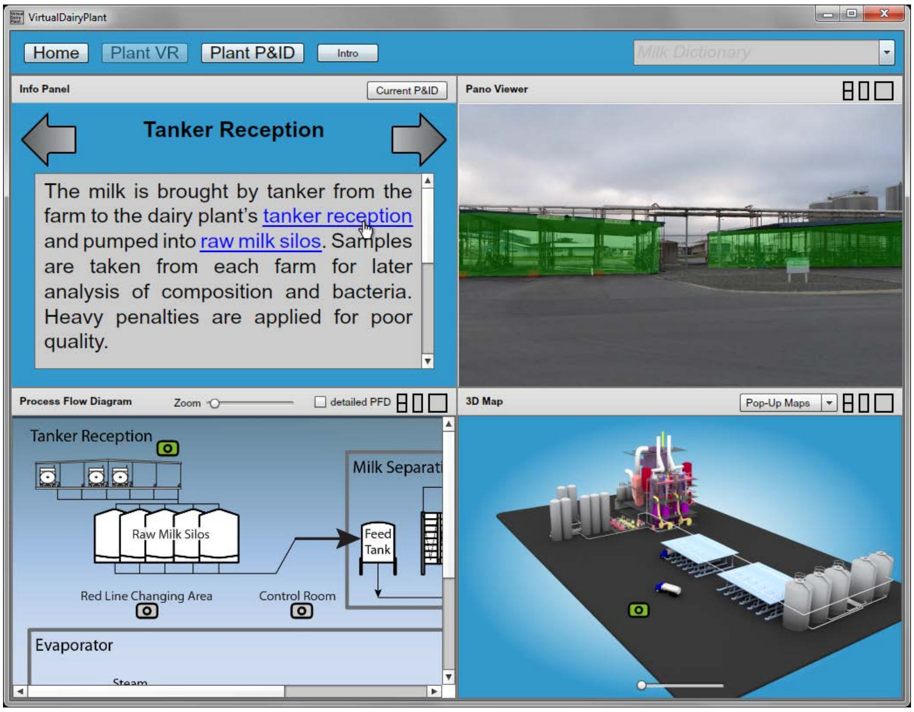

Fig. 1: The plant virtual environment displaying the different representations of the milk powder plant. The mouse is hovering over the "tanker reception" hyperlinked text in the info panel in the upper left quadrant causing the tanker reception in the photograph to be highlighted green. The node location is denoted by the green camera in the two lower quadrants.

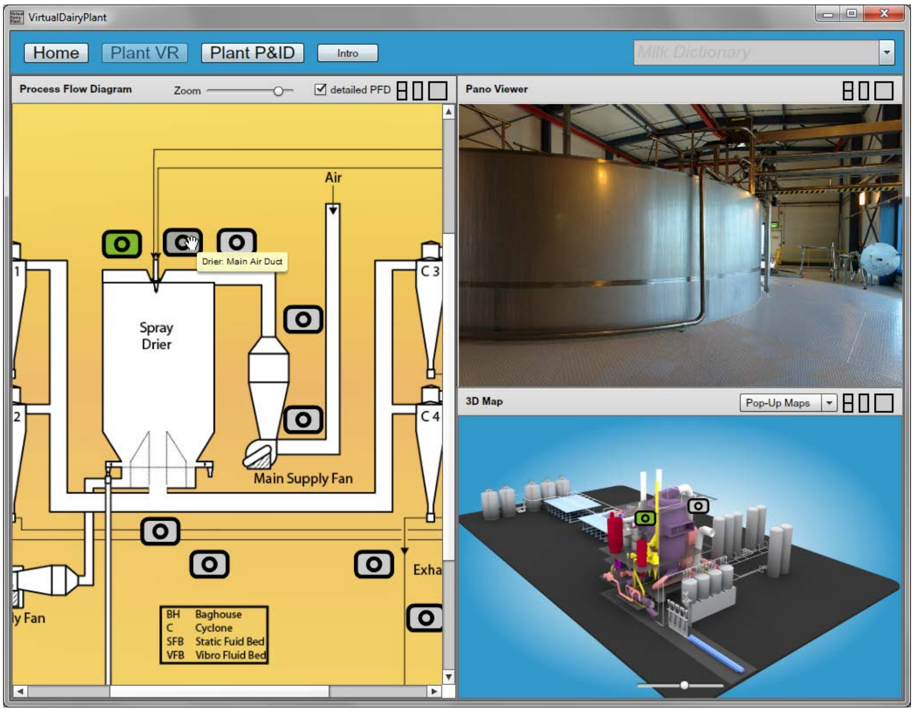

Fig. 2: Screen shot of the node preview feature with the active node indicated in green. The mouse is hovering over a different node in the PFD panel with a tooltip indicating the location of that node and makes the node visible in the 3-D diagram in grey.

APPLICATION EVALUATION

During the application's development period, several studies were conducted to test the user interaction, to evaluate possible areas of use and to compare the application's impact on learning outcomes to that of traditional course material.

Impact on learning

The undergraduate program in the Department of Chemical and Process Engineering at the University of Canterbury is a four-year program that currently enrols approximately 60 students per year. To investigate the immersive learning package's impact on learning and to identify weaknesses, ENCH 394, a 3rd year course on process engineering design, provided the testing environment. ENCH 394 covers heat exchanger design, risk reduction techniques, basics on material science and an introduction to the UniSim™ and SuperPro Designer™ process simulation packages. Students attending this course have a basic knowledge of process engineering and are accustomed to self-study.

Procedure

An assignment contributing 10% to the total mark of the course was thought to provide the right incentive for the students. For the task, the class was divided into two evenly distributed grade point average (GPA) cohorts to allow statistical comparison. The GPA calculated was the average of each student's course grades from the previous year. In New Zealand, the course grade points making up the GPA range from 'A+' = 9, down in decrements to the failing mark 'D' = 0.

Sixty-two students completed the assignment. The two cohorts received different sets of course material and had one week to study. At the end of the week, the students sat a closed-book, 1.5 hours test. The course material for cohort "Multimedia" consisted of the immersive learning application with a reduced information (only containing 18 nodes). The application was installed on a server and could be launched from desktop computers located in two computer suites. Only students from cohort "Multimedia" were given computer rights to launch the application. The course material for cohort "Conventional" was a 35-page document derived from the modified immersive learning application. The text information consisted of the information found in the "Info" panels and the more detailed information from the interactive legends. PFD and P&IDs were modified and integrated into the document. Photographs and animation material were not included in the conventional course material. Upon starting the assignment, the students were assembled and the task was explained. Cohort "Conventional" received the paper hand-outs and cohort "Multimedia" gained access to the application along with a brief explanation of how to drive the software. During the session, the purpose of the two cohorts was explained and students were asked only to use the material given to them and not to share it. In addition, students were asked to keep track of their time spent studying the material. Final grade scaling was performed to adjust the two cohorts to enable fair student outcomes for course assessment.

For the evaluation of the learning outcomes, the effect size provides an indication of practical meaningfulness (Fan, 2001, Kotrlik & Williams, 2003, Rutten *et al.*, 2011, Wiliam *et al.*, 2004). The effect size factor used to quantify the differences between the two cohorts was Cohen's *d*, which measured the difference between means, based on their pooled standard deviations (Cohen, 1988).

The interpretation of Cohen’s *d* effect size scores are:

< 0.2 small effect size

~ 0.5 medium effect size

> 0.8 large effect size

After the test students were surveyed to assess the learning style of the individual student. A shortened version of the index learning style questionnaire, adapted from Felder and Solomon (1991), was used to identify visual or verbal learners. The visual learners refers to people who learn best from what they see (i.e.: diagrams, pictures, demonstrations, etc.) and verbal learners learn best from words in a form of written or spoken. Everyone learns more when information is presented in both visual and verbal format (Felder and Solomon, 1991).

Results

It took the students an average of one hour to answer the questions in the closed-book test. On average, the Multimedia students reported studying the application for approximately 6 hours, whereas Conventional students studied 30 minutes longer. For both groups, the study time ranged from two and a half to ten hours.

For the overall test assessment, the immersive learning application had a medium effect on learning. Figure 3 shows the individual marks distribution according to the students’ grouped GPAs. The total averaged marks and their standard deviations were 62% ±11% and 69% ±12% for Conventional and Multimedia cohorts, respectively. Each group consisted of 31 students, which resulted in a Cohen’s *d* of 0.57.

An interesting aspect was the increased performance of lower GPA students studying the immersive learning application compared to students studying the conventional material. In particular Multimedia students with GPAs between C and C+ achieved substantially higher marks than Conventional students in this GPA range. The combined averaged marks and corresponding standard deviations were 74% ±4% and 61% ±6% for Multimedia and Conventional students, respectively over this grade range. The total number of students between a GPA of C and C+ was 15, which included 8 and 7 students in the Multimedia and Conventional cohorts, respectively. In addition, in this GPA range, the Multimedia students also spent less time on the material than the Conventional students (4.3 h vs 5.4 h). This finding indicates that the immersive learning application had a large effect on learning outcomes for students in the GPA range of C and C+. Further research is needed to draw firm conclusions about this but we might speculate that students with a GPA in the range C to C+ may be capable but have weak study skills that benefit from the more organized, sequential presentation of material in the immersive learning tool.

For students in the GPA group B, the average marks and their standard deviations were 70% ±6% and 62% ±7% for Multimedia and Conventional students, respectively. This group consisted of 8 Multimedia and 9 Conventional students, which results in a Cohen’s *d* of 1.2. The result indicates that the immersive learning application has a large effect on learning for students with a B GPA. For students with a GPA of B-, no impact on learning was found (Cohen’s *d* of 0.16). Groups above a B GPA consisted of 4 or fewer students and therefore the authors dismissed any further statistical comparisons.

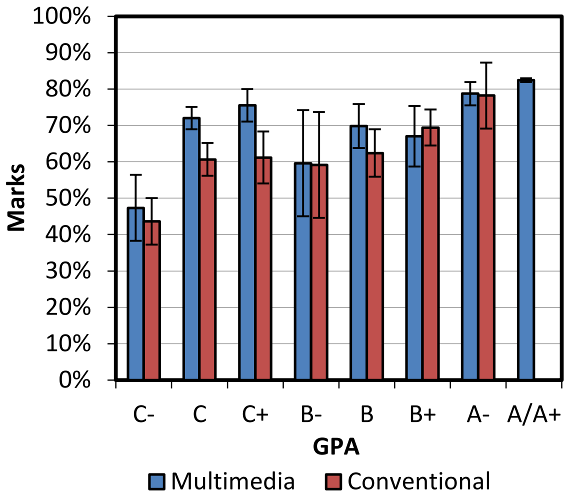

Fig. 3: GPA grouped test results for ENCH 394.

The index learning style questionnaire identified that majority of the students from both groups were prone towards the visual dimension compared to the verbal dimension. Students with preferences towards the verbal dimensions were expected to perform better in the Conventional group and students with preferences towards the visual dimensions were expected to perform better in the Multimedia group. The results however did not demonstrate this as the mean scores of the total marks for students in the Multimedia group were higher in all except for the students with mild preference of visual dimension.

Usability study

This study aimed to evaluate the usability of the application and the clarity of the user manual included in the application.

Procedure

Eight students (3 males and 5 females) were recruited where four of them were second-year chemical engineering students and the remaining four are fourth-year students. The participants were first briefed about the procedure of the session. The first part of the session was the practice session where the participants were asked to learn using the application based on a printed user manual. No demonstration was given as they were expected to be able to navigate based on the information provided in the user manual. The participants however were allowed to ask questions should there be any confusion or difficulties during practice session.

Once the participants completed the practice session, they were asked to perform a set of prescribed tasks which covered the available features in the application. During this session, the participants were allowed to refer to the user manual while performing the task. Upon the completion of the task, the participants were asked to complete an adapted questionnaire (Lund, 2001), which required the participants to rank statements covering ‘Ease of Use’, ‘Ease of Learning’ and ‘Satisfaction’ on a scale from 1 = Strongly Disagree to 7 = Strongly Agree.

Results

The results indicated that the application was rated high (on a scale from 1 = Strongly Disagree to 7 = Strongly Agree) in terms of Ease of Use (Median = 5.8), Ease of Learning (Median = 6.5), and Satisfaction (Median = 6.5).

Virtual field trip study

Procedure

Nineteen fourth-year chemical engineering students volunteered to participate in this study. Ten of them had recently attended a physical field trip and the remaining nine did not attend. The trip did not include a dairy plant. The students were split into four groups – where two groups consist of students who attended the physical field trip (five students for each group) and the other two groups consist of students who did not attend the physical field trip (group size of five and four students).

For each group, a guide, with in depth knowledge of the process plant, introduced the process and led the participants through the virtual tour. Similar to a physical field trip, the session were interactive where both the students and the guide discussed what they were seeing and exchanged questions and answers throughout the session. Only the guide operated the application while the students watched and listened to the explanations given. Figure 4 shows the environment where the sessions took place (average sessions time: 35 – 45 minutes).

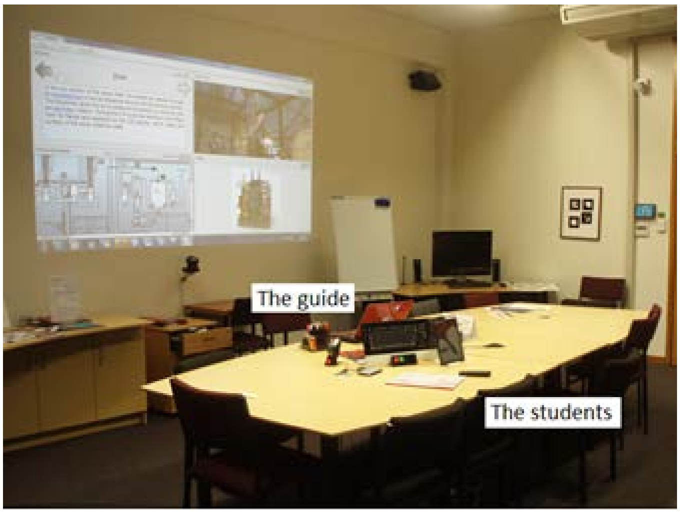

Fig. 4: The environment for the virtual field trip session.

Results

At the end of the session the students were asked to fill in a questionnaire. The results (Fig. 5) suggest that the virtual field trip could be used as an alternative for a physical field trip where a physical site visit is not available, similar to findings by Harrigton (2009).

For the question "*The application could be used in place of a physical field trip*", the responses received from students who attended the physical were inclined towards disagreement (Median = 2) compared to students who did not attend the physical field trip (Median = 4). The main reasons for the disagreement were social aspects (the fun factor, hanging out with mates) and real world experience (smell, noise, dust) associated with a physical field trip, which cannot be reproduced by the application. However it was noted that noise and distance from the tour guide inhibited learning during physical field trips in some instances.

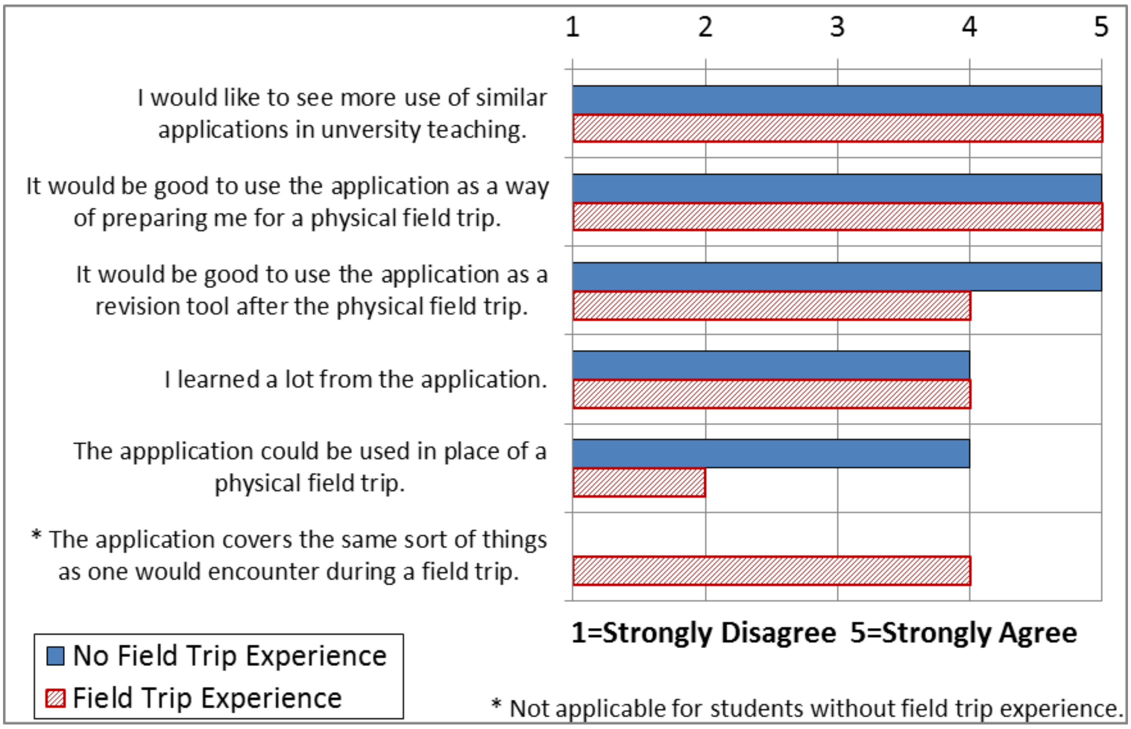

Fig. 5: Summary of the virtual field trip questionnaire.

CONCLUSIONS

An immersive learning application has been developed for the milk powder production process. During the usability study, the participants did not face any major issues when using the application either during the practice or when performing the navigation task. Most participants found the application was easy to use and the links between each component in the application helped them to have a better understanding on the milk processing.

In case an actual field trip is not possible, the field trip study showed that the application would be accepted as an adequate replacement. Students from both groups of the field trip study agreed that the application would be a good tool to be used as a preparation (pre) and a revision (post) tool for a physical field trip. They also agreed that the application was a good learning tool and they would like to see more applications in university teaching.

The learning effect analysis shows that learning outcomes can be improved by the immersive learning application but that structured information must be consistently implemented in the information delivery flow. Although at present the application has a medium positive effect as measured by Cohen's *d* analysis, the authors are confident that once the application is completed, particularly incorporating a more explicit display of some information currently "hidden" behind buttons, its effect on learning will be further enhanced. However the learning style preferences did not influence the learning outcomes, which suggest that the application can be used for visual as well as verbal learners.

The increased performance of weaker students using the immersive learning application needs to be investigated further, both to determine its statistical significance and to identify possible causes, for example taking into account the learning style preference of test groups.

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BRIEF BIOGRAPHY OF PRESENTER

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