Potentials and Challenges of Using Mixed Reality in Mining Education

A Europe-Wide Interview Study

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***Abstract*—Mining engineering and its educational sector are continuously affected by different transformations. In this regard, the number of students is constantly declining. Universities and educational institutions are struggling for financial resources to maintain the attractiveness of mining education. In particular, real-life experience gained through excursions is indispensable for the success of mining education, but also expensive to offer. A possible solution to meet these challenges is the usage of Mixed Reality based tools in teaching. This technology allows otherwise hardly accessible or dangerous scenarios to be experienced directly in the classroom. This paper presents the results of a European-wide interview study, in which the potential, chances and risks of the technology for the field of mining education are questioned. From the results, first indications for the use of Mixed Reality tools and further demands for research are derived.**

Keywords-Mixed Reality; mining education; digital teaching; interview study; MiReBooks project.

I. Introduction

In the recent past, there have been major changes in the industry, which had a significant impact on the mining sector [1]. In the context of declining the economic importance of mining in many countries, unprofitable mining operations are closed down and state-controlled mining operations are increasingly being privatized. Moreover, the declining social acceptance of the raw materials industries deteriorates the public image of the mining industry, as it is seen as "a dangerous and environmentally damaging low technology industry"[1].

Despite the steadily increasing demand in the sand, gravel and quarry industry and the growth in minerals production, mining is becoming less and less attractive for students [2]. Although the mining sector continues to offer attractive job prospects, study numbers continue to decline. In addition, it is evident that the main focus of public investment is on growing and economically promising courses of study, which is why mining departments are suffering from severe financial cutbacks [1].

To prevent further decline and make mining engineering more attractive, industry and research have to cooperate closely and develop concrete measures [2]. Shields and colleagues emphasize, that especially in the education of mining engineers, we have to face the challenges of a new world in order to meet both present and unforeseen challenges [3]. Subsequently, engineering education has to enable new and broader perspectives "by incorporating the complexities of environmental, economic and social realities along with systems engineering, enabling technologies and physical constraints" [3]-[5]. In addition, knowledge should be provided in a holistic and transdisciplinary manner, and thus also transnationally [6].

This holistic knowledge also includes the acquisition of interdisciplinary skills beyond technical knowledge [7]. Allenby states in 2011: "while most engineers are technically competent, they lack communications ability and they do not understand the context within which they are expected to perform professionally" [8]. Moreover, mining engineering graduates often have little understanding of how to transfer their theoretical knowledge into practice [9].

Taking these requirements into consideration, the MiReBooks (Mixed Reality Books) project was launched in 2018 [10]. MiReBooks is a project funded by the European Institute of Innovation & Technology (EIT) Raw Materials that consists of a pan-European consortium with over 14 partners. The project addresses the current problems in the field of mining education. In particular, the focus is on increasing the attractiveness of mining engineering as a field of study. To this end, measures to increase the quality of studies are being developed. Within the project, the transfer of theoretical knowledge into practice is of particular importance. In a situation in which mines are hardly accessible and excursions are very expensive and time-consuming, teaching institutions have to find new methods to facilitate the transfer of knowledge. Thus, MiReBooks produces a series of Virtual Reality (VR) and Augmented Reality (AR) based interactive mining handbooks as a new digital standard for higher mining education across Europe. The project aims to change the way students are taught by empowering teachers to engage their students more effectively and provide them with a wider repertoire of content and better understanding.

This paper gives an overview of the potentials and threats of using Mixed Reality (MR) based technologies in mining education. For this purpose, an interview study with 39 participants (teachers and students) was conducted to assess the need, possible application scenarios and the opportunities and risks of MR in teaching. Section 2 presents the current state of MR tools in education. In Section 3, the method and framework of the interview study is presented. The results are presented in Section 4. Subsequently, a discussion of the main findings and an outlook can be found in Section 5.

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II. Mixed Reality in Education

After more than twenty-five years of educational research, MR tools are increasingly finding their way into education [11]. Describing a continuum between reality and virtuality, MR enables to merge physical and digital worlds [12]. Thus, technologies such as AR or VR can be subsumed under the framework of MR. Within the context of teaching, AR augments the real world by placing virtual content (such as 3D models) into the field of view or provides further digitally displayed information (e.g., through annotations) to a real setting [13]. VR enables the user to experience the feeling of presence in a fully modelled, virtual environment [12].

According to Dede and colleagues, these media offer new "opportunities for enhancing both motivation and learning across a range of subject areas, student developmental levels, and educational settings" [11]. In addition, they state that MR experiences enable situated learning, which is widely acknowledged as a powerful didactic concept [14]. Thus, MR offers to experience and learn how to deal with problems or situations that are similar to the real world. Especially in mining education, students could experience important procedures and processes that are usually hardly accessible in the real world. Other promising fields of application are, for instance, in the education of engineers [15] and medical specialists [16].

By providing these opportunities, MR is able to further address the crucial factor of knowledge transfer [17][18]. Students can build a strong connection between their theoretical knowledge and a practical task or workflow. Thus, a replication of real processes in simulated environments can support the training of relevant behavior for performance in work or personal life [15]-[19]. In addition to that, collaborative forms of MR can foster communication and problem-solving skills by enforcing interaction with other students to jointly perform a task [20]. This can even be offered time and place independent. As a result, MR is expected to be able to address current challenges in mining education, such as:

1. offering experiences in otherwise hardly accessible settings [11][21],
2. enhancing motivation and learning and thus making mining more attractive for students [11][14][21],
3. fostering knowledge transfer and enhancing the development of professional skills [17][18],
4. allowing students to control their learning processes more actively [22],
5. and enabling a lasting learning-effect through game-based formats and the possibility of immediate feedback for actions and decisions [23].

The positive effects of MR in education were also confirmed by lecturers, who considered the use of the technology to be helpful [24].

However, there is still little knowledge on how and when to use these media in mining courses [10]. Questions relating to which applications are particularly suitable to be presented in MR or which positive and negative effects can be expected from their use remain unclear.

Based on twelve MR-based test lectures at different partner universities of the MiReBooks project (four on open pit bench blasting, three on hard rock underground drift development, two on hauling in mining, and another three on continuous surface mining), a broad qualitative interview study was conducted. Within these lectures, different sets of hardware components were presented (standalone and computer-connected VR headsets; such as HTC Vive (virtual reality headset developed by HTC and Valve), Oculus Go and Oculus Quest, AR-enabled smartphones and a local-network-based solution for connecting different VR headsets). During the test lectures, classical teaching materials were used (presentation slides, whiteboards, blackboard) and combined with small breakout sessions to provide MR-based experiences. Within the interview study, we addressed teachers and students with or without experiences with MR. Thus, we assessed general requirements in mining courses and aimed to find out which strengths and threats are associated with using MR based technologies in mining education.

III. Method

A. Study Design

Within the interviews, different perspectives of both teachers and students were considered. Furthermore, the aim was to interview not only those who already had experience with MR in the course of the test lectures. The majority of students and teachers in the field of mining have no previous experience with MR. Therefore, this target group was also considered in the present study. In summary, we interviewed four different target groups. We aimed at collecting feedback from experienced teachers, who conducted the test lectures, as well as inexperienced teachers, who did not use MR technologies in any lecture before. Furthermore, experienced students who took part in the test lectures, as well as inexperienced students were interviewed.

The experienced group of teachers and students, who conducted or took part in a MR-based test lecture, were asked in particular about their experiences with MR. The interviews with the experienced teachers were especially focused on their reflection of the test lecture, with special emphasis on the necessary preparation and optimal teaching conditions. The questions to experienced students served primarily to obtain feedback on how they perceive the use of MR in comparison to classical lectures. Furthermore, they were asked about perceived advantages, disadvantages and possible difficulties using MR. Inexperienced teachers were asked which media they currently use, whether they would be interested in using MR and what would be necessary to enable them to give their own lectures with such technologies. Inexperienced students were asked about their experiences with current teaching methods. Subsequently, they were asked whether it is possible to provide more realistic insights in mining processes through the use of MR. Additionally, we asked about potential meaningful application areas and student's general expectations with regard to benefits or threats using MR. All interview guidelines included questions on the effective communication of learning content, areas of application and opinions on problems.

The interview guidelines and number of questions varied between experienced teachers (10 questions), inexperienced teachers (12 questions), experienced students (8 questions) and inexperienced students (11 questions). The interviews were conducted either face to face or in written form. The average duration of an interview lasted between 15 to 30 minutes, where the written answers were often rather brief. The interviews were then anonymized and transcribed in order to analyze the entire data in a qualitative content analysis using software.

B. *Participants*

In total, 39 participants took part in the study. Overall, three experienced and three inexperienced teachers, as well as 21 experienced and twelve inexperienced students from five different universities all over Europe (Germany, Austria, Estonia, and Sweden) were interviewed for the study. The participants were recruited via project partners and posters of the project. Participation in the interviews was voluntary. Participation in test lectures was also voluntary. All students were from different semesters and study courses. The requirement for students to participate in the interviews was that they were currently enrolled in a mining-related subject. The teachers should also have experience in mining-related teaching.

C. *Qualitative content analysis*

The purpose of content analysis is to analyze communication that has been recorded for example in texts, images or other symbolic material. For this, a systematic, rule-guided and theory-based approach is used, which allows to draw conclusion about specific aspects of the communication [25]. The key to this is the definition of precise categories that capture the substance of the investigated content.

There are deductive methods in which a-priori categories are defined, according to which the contents are later sorted and analyzed. Other methods proceed inductively and extract the categories completely from the data itself. In general research practice, the existing categories from the interview guidelines are used first. Second, further subcategories are derived inductively on the basis of the data [26].

Since the aim was to generate new hypotheses about the potential and risks of using MR in mining education through the qualitative research approach and to open up new fields of research by dealing with pre-structured interviews in an interpretative way, the deductive-inductive categorization approach described by Kuckartz was chosen [26].

After reading the material carefully, the interview statements were coded for the first time according to categories that corresponded to the direction of the questions in the guidelines. As a result, irrelevant information could be excluded and longer answers could be subdivided into different units of meaning, whereby multiple coding of a sentence was possible. Subsequently, the coded statements within the categories were grouped by meaning, divided into different subject areas and described with the use of short summaries. These summaries served as a basis to define specific and clearly distinguishable criteria by which all data should be re-coded and finally analyzed.

Some of the categories were reorganized in order to make them more suitable to grasp the substance of the statements made. This form of revision of categories is intended, since the development of categories can be seen as a continuing iterative process in which, the categories are reflected upon and rearranged.

Because the answers, especially in the written interviews, were very short, covered very different questions and therefore did not form a coherent narrative, we refrained from preparing case-related thematic summaries suggested by Kuckartz [26]. Instead, the different categories and sub-categories of each interviewed group were summarized and examined.

The following section provides an overview of the derived categories and sub-categories and summarizes the related statements.

IV. RESULTS

A total of four main categories were defined. First, an overview of (1) media currently used in teaching is given. Secondly, the (2) changes in the learning experience resulting from using MR are presented. Three subcategories were formed in this section, which can be seen in Table I. Another main category describes (3) possible use cases for the use of MR. Three further subcategories summarize for which target group the use of MR is particularly suitable, in which use cases benefit can be expected from the use of MR and when the use of MR appears to be particularly helpful. The fourth main category summarizes the (4) Lessons Learned resulting from the Test Lectures. The derived subcategories can be found in Table I.

TABLE I. OVERVIEW OF DERIVED CATEGORIES

Categories	Sub-categories
Currently used media	Classical methods and media
Changes in the learning experience	General benefits of MR
	Guidance through the lecture
	Individual learning needs
Application scenarios	Target group
	Use cases
	Alternative to field trips
Lessons learned from test lectures	Preparation for conducting MR lectures
	Technical aspects
	Integration of MR in the lecture
	Financial aspects
	Availability of MR content

A. *Currently used media*

In the course of the interviews with inexperienced students and teachers, questions were asked about the media currently used during lessons. The possible responses were semi-structured, as respondents could either choose from existing categories or add additional information. Students stated to use pictures and graphs, followed by texts and manuals (9), excursions and visits to mines (8) and videos and films (8). Only half of them stated to use 3D animations. Similar statements were also made by the inexperienced professors, who used all media except for 3D animations, which were rarely used. The teachers were also asked about the use of haptic objects like equipment, which all of them affirmed.

B. Changes in the learning experience

One of the aims of the study was to find out in what way the learning and teaching experience changes through the use of MR. Aspects included to what extent the technology helped to provide a more practical knowledge, what is perceived as more or less helpful during the test lecture and at which point potential problems arise.

1) General benefits of MR

A large majority of 18 students who had previously attended the lectures agreed that the MR technology used was of immense benefit for practical understanding, or at least has great potential. The reasons given for this were that the used technology conveyed a feeling of reality and of actually being present in the situation, which led to a much better imagination of the machines and processes presented.

According to the respondents, the 360° videos, e.g., from the perspective of a machine operator, provide a more practical perspective and a potentially faster transfer from theory to practice. This experience of a more practical understanding through the use of the technology in the test lectures largely met the expectations of the inexperienced students (8) and teachers.

More skeptical points of three experienced students referred to the fact that they already had knowledge about the presented content. Thus, they stated that real experiences cannot be replaced by MR and that the shown examples had little or no advantages over videos.

2) Guidance through the lecture

When asked about the test lecture, three teachers and nine students found it difficult to ensure that all students follow and understand the lessons equally while using MR.

These statements mainly refer to the VR glasses used, which restricted the eye contact between teacher and student. Whenever the teacher was unable to track the student's position within the virtually displayed environment, they reported that it was difficult to ensure that students pay attention to the relevant aspects of the content presented.

For this reason, and since the impressions and amount of information can be "overwhelming" (as one experienced student and one inexperienced teacher put it), it was considered very important by many respondents that some form of helpful guidance through the situations is provided.

One of the teachers observed during the test lectures, that the material is not always self-explanatory and therefore "students still need guidance during their VR experience". Other reasons why students might be "lost" are that they want to play around with the technology and try out everything first, rather than deal with the actual content.

3) Individual learning needs

Three experienced students said that students first need some time to get used to the new technology. Otherwise, it may be difficult to listen to the lecturer at the same time.

An experienced teacher pointed out that everyone has their own pace and type of learning. What he liked about MR was that it opens up different "paths" of teaching. "Therefore, virtuality offers a more individual learning environment", in which things can be learned independently at their own pace.

The freedom to discover and learn new things through their own actions seemed to be particularly exciting and important for some of the experienced students (5). For them, the interaction with the virtual environment could have been even more extensive, e.g., through the possibility of movement or additional tasks.

C. Application scenarios

The following section summarizes feedback on possible application scenarios. Moreover, it is presented for whom and in which contexts the use of MR is perceived as most beneficial.

1) Target group

In terms of the optimal target group, a large proportion of respondents (two experienced and one inexperienced teacher, ten experienced and three inexperienced students) agreed that the greatest benefit from the use of the technologies exists among students who have not yet had any real practical experience, for example, have never been in a mine.

According to students who took part in the test lecture, the learning effect might be significantly lower for students in higher semesters who have already visited mines several times during internships and excursions. This in turn corresponds to a teacher's impression that it was difficult to convey the content in an understandable and interesting way despite the differences in knowledge between the students. Another experienced teacher said that the benefits of MR highly depend on the content, which probably differs between bachelor and master students. Nevertheless, it was stated that both can still benefit from MR due to improved visualization.

2) Use Cases

There were many different answers to the question, which application areas for MR the interviewees could imagine. Safety trainings or demonstrations for a public target audience were named as use cases outside of a lecture. With regard to lecture content, different forms of visualizations and simulated scenarios were listed: e.g., underground mining, open pit mining or blasting, but also smaller practical processes, such as displaying the functioning or operation of machines.

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In general, particularly from the statements of the respondents from the test lectures, it can be derived that the teaching methods to be chosen and the technology used will depend strongly on the content to be taught. Although all experienced professors shared the opinion that MR provides added value by creating a feeling of reality, they emphasized that classical lectures, laboratory experiments or field demonstrations will still be essential in teaching students. According to the experienced professors (2), classical methods like calculations on a blackboard or the use presentation slides remain a better choice when it comes to teach scientific basics and principles or theoretical subjects, such as algorithms.

An inexperienced professor has particularly stressed that it would not be appropriate to teach content digitally, when a real use of instruments (such as measuring equipment) is needed. Both experienced and inexperienced respondents see the benefit of MR more in use cases, in which it can fulfil its illustrative function for otherwise hard to imagine processes. Compared to presentation slides or videos, MR might lead to a more in-depth understanding of the matter.

3) Alternative to field trips

A possible advantage of MR is that it could replace classical excursions to a certain extent through its realistic representation. However, both professors and students made contradictory statements in this regard, since real excursions are still considered an important part of education. Fields of application are therefore rather as a "virtual add-on" prior or after excursions enabling students "to have a feel of the process even before visiting", for example underground mines or providing additional information about a situation through an overlay of an already known situation. Since some sites for excursions are perceived as very expensive, far away or dangerous, the technology could also be used to introduce such rather special subjects.

D. Lessons learned from test lectures

The test lectures and the interviews with the different groups also contributed to clarify under which conditions MR can be used optimally and beneficially for teaching and what is necessary achieving this.

1) Preparation for conduction MR lectures

The teacher's preparation for the test lectures was mainly about familiarizing oneself with the technique in order to "foresee mistakes that students could do while being in VR". According to their own statements, all three inexperienced teachers would depend on external support in the preliminary stages of conducting their own MR lectures. This could be personal workshop trainings, or online offers like web platforms, because they need someone to show them "how to use the media".

In response to the question of how to prepare for the test lecture in comparison to a classical lecture, the professors said that they needed time to familiarize themselves with the technology used and the new teaching materials, e.g., 360° videos. One teacher stated that he received help from a PhD student for this.

2) Technical assistance during the lecture

The experienced (3) and inexperienced teacher (1) shared the opinion that some technical assistance is required to take care of the devices before, during and after the lecture. That means, "setting up the systems, bringing the systems to a classroom, putting them away, charging them", as well as solving technical issues currently still occur during the lecture. These personnel do not necessarily need to know anything about the content itself, but taking the responsibility for the technical functioning would ensure that the professor can focus completely on teaching of the content.

Possible technical issues, such as lack of synchronization or unstable Wi-Fi connection, were perceived as problematic, especially if students cannot have the same learning experience as others. One student therefore suggested to have a backup plan, such as following the experience on a screen or to provide material as a follow-up at home.

3) Amount of time

Based on their experience, the teachers said that in a 90-minute lecture, the MR experience should not exceed 30 minutes, otherwise it could bore the students or overwhelm them: "Too much VR might distract students from the considered topics. They need time to reconsider received portions of information, make appropriate notes, have contact with the lecturer, and ask questions." One suggestion, for example, was to show four to six 360° videos with a length of two to four minutes. A single five-minute video would be of little use and the technical effort would be considered too high. Another aspect worth considering, regarding the duration of MR use, is that (4) experienced students and (1) inexperienced students may find dizziness or cyber sickness a problem, especially if they are not yet used to the technology.

Some students also perceived switching between the presentation slides and the MR glasses as somewhat disruptive during the test lecture.

4) Frequency of use

The experienced professors expressed that the frequency of using MR depends very much on the respective contents and should therefore be decided flexibly and on a case-by-case basis.

After the test lectures, some students (6) shared the opinion that the use of MR can significantly improve teaching, but can also reduce the quality of the lectures if the technology is not integrated into the structure in a meaningful and purposeful way, for example, by reducing "the time you can talk with the students". In contrast, the prior explanation of the theory, in order to subsequently provide an immersive insight through MR, was a positively perceived example of the test lectures.

5) Amount of devices

As stated by one of the experienced teachers, the number of devices "depends on the media used and how many is available”. Two of the three professors and two students said that each student should have his own device at his disposal, otherwise the rest would get bored and the constant change would be seen as inconvenient. An alternative approach would be to use “one HTC Vive per 10 students for a 90-minutes lecture” and to mirror the experience on a screen.

6) Financial aspects

The cost of purchasing and maintaining equipment was considered as possible problem, which was estimated to be quite high. Directly related to this was the for now unanswered question of whether the university or the students themselves would purchase the equipment and thus be responsible for ensuring that the equipment would be available in a functional state for the lectures.

7) Availability of MR content

An experienced professor stated that the use of MR mainly depends on how quickly he can create his own MR content for the lecture. One experienced student stated that a prerequisite for its benefits was easy access to MR teaching materials. This was justified with the argument that the use of MR technologies in a virtual excursion could otherwise become too expensive.

The results of the qualitative content analysis are summarized and discussed in the following section.

V. Discussion

The aim of the interview study was to identify possible potentials and obstacles for the use of MR in mining education. For this purpose, 39 persons with and without experience with MR were interviewed about their experiences and expectations. The aim was to determine whether MR-based education can be considered a possible approach for meeting the current challenges in the mining sector. The results of the interviews provide first indications for the design and use of MR in mining education and point out further research gaps.

By interviewing different target groups, it was possible to ensure that relevant perspectives on the topic were covered. In further surveys, experts from mining operations should be involved in order to obtain their opinion on the transferability of MR-based content.

The findings are presented and discussed below, starting with the students’ perspective and then for the teachers’ perspective. Overall, the potential of MR-based teaching was seen by students and teachers. The learning advantages of MR can be clearly seen in the statements of experienced students. The students had the impression to get a more practical and deeper understanding of the content through the use of MR technologies. It was emphasized that the better visualization of objects, processes and the feeling of presence in virtual environments was perceived as beneficial in comparison to classical teaching materials. In current teaching, 3D simulations are only used in a few cases so far, but are considered helpful by students and teachers.

At this point, it was emphasized that inexperienced students are most likely to benefit from MR-based experience, e.g., to get an overview of the structure of a mine or to estimate the real size of machines. The advice of experienced students suggests that the use of MR in, e.g., master’s programs is more likely to be used for advanced processes - for example, to be able to observe blasting in slow motion. Another relevant aspect relates to the possibility of individualized learning. Thus, different levels could be realized by the mentioned possibilities to go through learning experiences at individual pace and with individual prerequisites.

With regard to the teachers’ perspective, it should be ensured during the lecture that there are opportunities for interaction with the students. Otherwise, there might be the danger of a loss of control over the lecture or the challenge to direct student’s attention to the relevant aspects of the content. Interaction can either directly be integrated in the MR experience using arrows, annotations or external control of the headsets. Alternatively, it is possible to offer the teacher a control mode on the PC screen so that he/she does not have to wear a head mounted display.

Various aspects should be ensured when preparing an MR-based learning experience. The teachers pointed out that the technologies should be used in a very content-oriented way and be integrated in existing teaching concepts. The inexperienced professors agreed that the benefits of MR technologies depend on what content and how it is used. They rather saw it as a meaningful virtual extension to classical teaching concepts, such as lectures, experiments or excursions. For the creation of MR-based learning experiences, guidance should be offered on choosing the appropriate medium for a respective learning goal.

Furthermore, a need for some technical assistance was pointed out, in order to be able to fully concentrate on the students and the lecture. In any case, both students and teachers should be given the opportunity to get used to the technology. This can avoid that someone feels insecure and cannot concentrate on the content.

The selection of devices and time slots in which MR is used depends highly on the content. However, many teachers emphasize that uncontrolled use of MR can be overwhelming: Therefore, before using MR, teachers should always reflect on the learning goal to be achieved. This is supported by the statements of the experienced students, expecting MR to be beneficial only if it is well integrated into teaching.

VI. Conclusion

The aim of this work is to derive possible advantages and disadvantages of using MR technologies in mining education. In summary, the following implications can be derived for the challenges mentioned above. Especially experienced teachers saw the potential of MR in offering experiences in otherwise hardly accessible settings. This means for the further elaboration of the topic and future research that transparency about the possibilities of MR technologies should be established. Especially in case of teachers or students who had already experienced MR in class, they were able to imagine further scenarios.

Regarding the possibility of enhancing motivation, providing better learning experiences and thus making mining more attractive for students, MR and its application in mining education shows great opportunities, but must definitely be further investigated. Only if MR is accepted by teachers and used efficiently, it can contribute to the achievement of learning goals and thus be attractive for students. An important step is to guarantee low-threshold tools and platforms in order to use MR for teaching purposes. Prototypical applications should be publicly available and accessible throughout Europe.

The interview result shows that MR seems to offer new ways of fostering knowledge transfer. Concerning the development of professional skills, there should be more research on collaborative solutions and scenarios in MR to enforce communication between students. Nevertheless, this approach should be discussed and validated by involving experts from industry.

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