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Fostering Motivation toward Chemistry through Augmented Reality Educational Escape Activities. A Self-Determination Theory Approach

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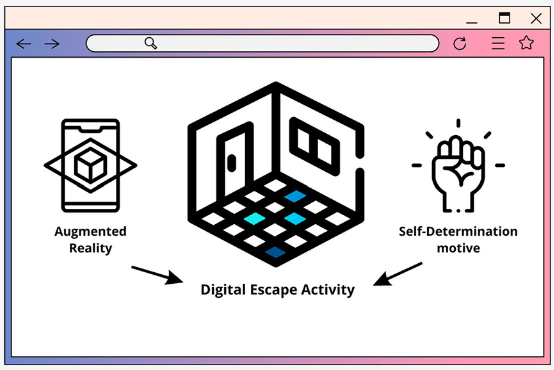
ABSTRACT: There is little doubt that motivation influences the extent to which individuals engage with online learning experiences. With the increasing role of digital technologies within chemistry higher education, this study illustrates how an augmented reality (AR)-supported educational escape activity (EEA), based on topics of inorganic stereochemistry, can be employed within an online environment. The design aspects of our activity were guided by principles of Self-Determination Theory (SDT)—an intrinsic-extrinsic theory of motivation. We sought to actively support the fundamental needs of competency, autonomy, and relatedness. Our control group was provided with a copy of our EEA that utilized two-dimensional drawings. Reported measures of competency were seen as a positive predictor of intrinsic motivation. However, in this study, this was not observed to be a positive predictor of academic performance. The introduction of AR, over and above the EEA, did not result in any significant differences in reported intrinsic motivation or post-test scores on our stereochemistry test instrument. Collected qualitative data suggest that participants found the activity to be useful and engaging. Through students' discussions, we have provided evidence of how design aspects of the EEA support the psychological needs satisfaction outlined by SDT. The design of our EEA provides one approach to implementing this style of learning activity, in a way that supports virtual presence and is scalable to large student cohorts.



KEYWORDS: *First-Year Undergraduate/General, Collaborative/Cooperative Learning, Humor/Puzzles/Games, Computer-Based Learning, Problem Solving/Decision Making, Stereochemistry*

Higher Education Institutions have experienced a precipitous shift into online learning, with educators facing challenges in maintaining student engagement and motivation. Given the important reciprocal relationship between motivation and learning,[1] exemplars of multimodal innovations in pedagogical strategy, afforded by advancements in information and communication technology (ICT), have surfaced to increase motivation, while supporting students' understanding of chemistry concepts.[2] One example, built upon the paradigm of Game-Based Learning (GBL), is educational escape activities (EEAs). An EEA contextualizes educational content, using principles of GBL, into meaningful, collaborative experiences, within a unique learning environment.[3] Participants accomplish tasks, developed around the subject content, to achieve a team goal within a set time.

The earliest documented escape room activity was developed by SCRAP in 2007,[4] as a single-room activity for teams of 5−6 participants. This model rapidly spread through Asia and Europe, with the World of Escapes directory listing more than 18,000 different escape room activities in more than 45 countries as of June 2022.[5] In an educational setting, their potential as learning activities has inevitably attracted the attention of researchers. EEAs are reported to be positively perceived among students[6,9,11,13,14] and have shown great value in terms of engagement,[6,11−14] motivation,[6,7,12,14] and learner outcomes.[7,8,10] Reviewing educational literature that deals with chemistry-specific EEAs outlines previous examples that serve as (i) instruction to lab techniques,[15−18] (ii) evaluation of student understanding,[19−22] and (iii) complementary teaching of concepts.[23,24] Digital variants of the traditional EEA, supported by immersive technologies such as augmented reality (AR), for online learning are the latest development, allowing for the scalability required for implementation in larger educational settings.

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INTEGRATING AUGMENTED REALITY

The advancement of ICT has increased education coverage through digital media, while also offering diverse learning experiences.[25] Specifically, the approach of AR provides an interactive experience through enhancement of a physical environment by virtual information, across a single or multiple sensory modalities,[26] and can be accessed by students through their personal mobile devices. For applications in chemistry education, AR can offer recognition and contextual support. Students can scan image targets, which are dynamically cross-referenced with an application's database to generate a virtual object. Virtual objects can then be manipulated by students using simple finger gestures. Embedding virtual experiences has shown to have strong motivational implications, by engaging students in active learning based on situated experiences in applied contexts.[27−31]

The subsequent blending of EEAs and AR technology is logical, and education researchers are starting to investigate this integration and its influence on learning outcomes.[32−35] The comparatively low cost of implementing AR technologies into the classroom on ubiquitous devices provides an opportunity for rapid virtual presence. The vision of this project draws on the inspiration of using AR to support this pedagogy. Our narrative environment serves as a context for students to enhance their understanding of stereochemical concepts in coordination chemistry,[36] while also developing their visual literacy through interaction with AR technology.[37] We believe this paradigm has enormous methodological potential.

SELF-DETERMINATION THEORY

Many educators are concerned with motivational research.[38−42] The interplay between the extrinsic influences acting on an individual and their intrinsic motives is central to Self-Determination Theory (SDT), a framework for understanding factors that affect an individual's inherent motivation.[43] One current direction of SDT research concerns the utilization of emerging technologies, such as AR and GBL, for education.[38] As intrinsic motivation is fully autonomous, it is relevant to educational settings and has been shown to be consistently associated with higher performance.[44] Expanding further, those who experience pressure from external regulations to conduct a desired behavior, who are extrinsically motivated, are very likely to feel an innate need to internalize these regulations. The more successful the process of internalization, the more these suboptimal extrinsic regulations echo the characteristics of intrinsic motivation. SDT assumes that humans are inherently prone toward psychological growth and integration and, thus, toward learning, mastery, and connection with others.[45]

To achieve high-quality forms of motivation and engagement, three needs are seen as fundamental: autonomy, competence, and relatedness.[45] Autonomy concerns a sense of initiative and ownership in one's actions. It is supported by experiences of interest and value and undermined by experiences of being externally controlled, whether by rewards or punishments.[38] Competence concerns the feeling of mastery, a sense that one can succeed and grow. The need for competence is best satisfied within well-structured environments that afford optimal challenges, positive feedback, and opportunities for growth.[38] Finally, relatedness concerns a sense of belonging and connection.[38] The thwarting of any of these three basic needs, possibly as a result of flawed learning activity design, is seen as detrimental to motivation. Accordingly, SDT's analysis of educational settings is primarily focused on the extent to which they meet or frustrate these basic needs.[46] Hence, we have focused on how an EEA embedding AR technology, as a tool for learning, can be developed around these three fundamental needs, to bolster engagement and learner outcomes.

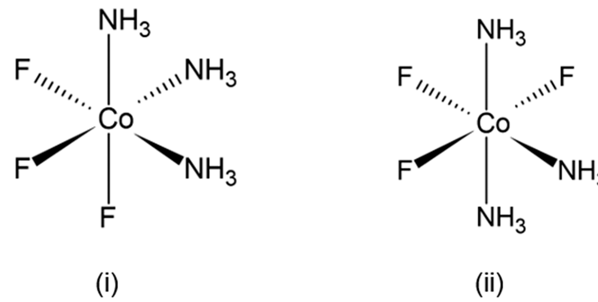
TEST INSTRUMENTS

The following test instruments were employed throughout this study:

Isomerism in Transition-Metal Complexes (ITMC) Test Instrument

The ITMC is designed to assess higher education chemistry students' understanding of important topics of isomerism in transition-metal complexes. Responses are scored as correct or incorrect, which are then aggregated to yield the total score. The instrument contains 10 items in a multiple-choice format (Figure 1, for full instrument, see Supporting Information), which are organized under three concepts important for developing proficiency: rules of nomenclature (items 1−3), stereoisomerism (items 4−6), and structural isomerism (items 7−10). Content validity was conducted on the instrument prior to this study.

6. Two isomers of coordination compound [$Co(NH_3)_3F_3$] are shown below. The isomers can be classified as:



a. (i) fac-isomer (ii) mer-isomer
b. (i) optical isomer (ii) trans-isomer
c. (i) mer-isomer (ii) fac-isomer
d. (i) trans-isomer (ii) cis-isomer

Figure 1. An example of an item on the ITMC test instrument.

Intrinsic Motivation Inventory (IMI)

The IMI is a multidimensional measurement instrument intended to assess participants' experiences in relation to a target activity. The instrument yields seven subscale scores.[47] These are (i) interest/enjoyment, (ii) perceived competence, (iii) effort, (iv) value/usefulness, (v) felt pressure and tension, (vi) perceived choice, and (vii) relatedness. The interest/enjoyment scale is considered the self-report measure of intrinsic motivation.[47] Past research suggests that order effects of item presentation appear to be negligible, and the inclusion or exclusion of specific subscales appears to have no impact on the others. Previous application, and resulting analysis, has shown strong support for its validity.[48,49]

ChemFord

A free augmented reality mobile and tablet application is available on Apple iOS (iOS 11.0 or later) and Android (4.4 and up) platforms developed by the authors.[21] ChemFord allows the

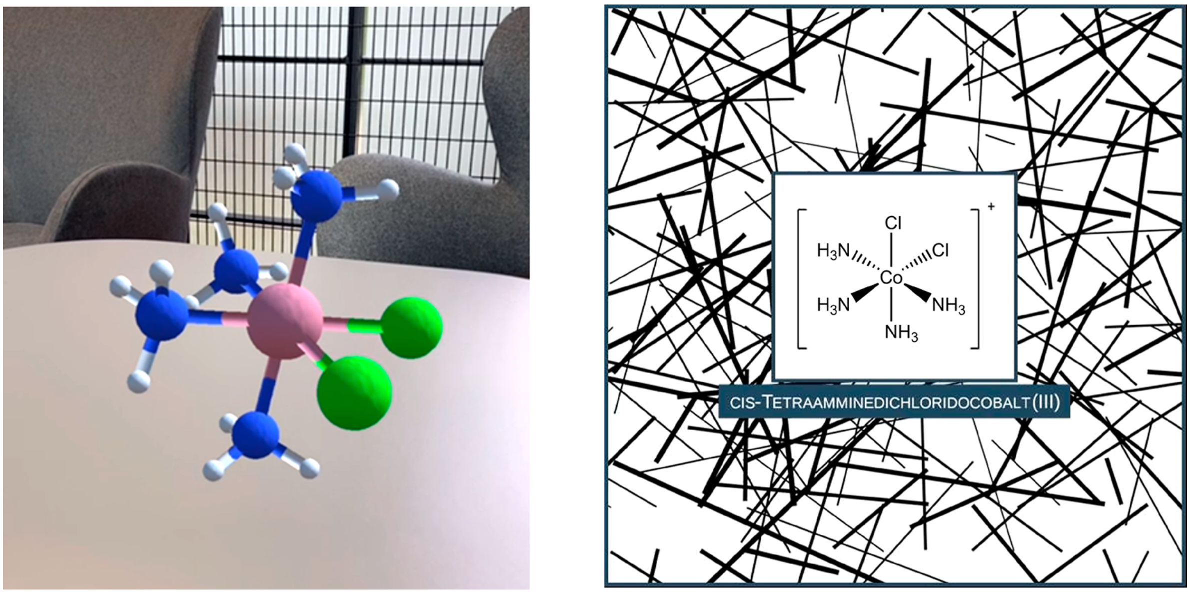


Figure 2. An interactable 3D representation of *cis*-tetraamminedichloridocobalt(III) (left), visualized using a ChemFord image target (right).

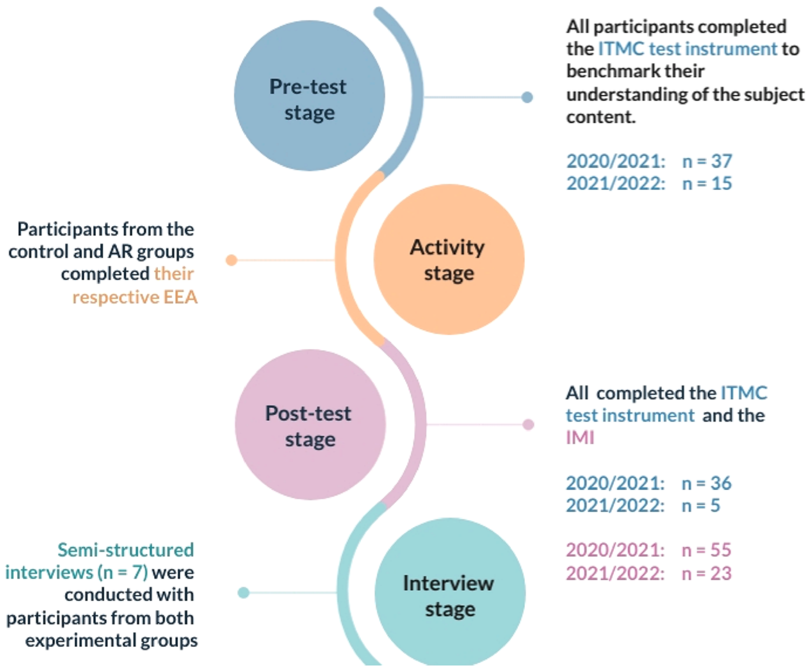


Figure 3. Experimental design utilized for this study, including details of participant engagement.

generation, and direct manipulation, of over 200 unique virtual objects pertaining to areas of chemistry including, but not limited to, molecules and lattices, metal complexes, atomic and molecular orbitals, and VSEPR geometries. Virtual objects are instantiated by scanning an image target (Figure 2) or by using ChemFord's object inventory, a markerless AR approach.

PARTICIPANTS AND PROCEDURE

This research was conducted with two different student cohorts throughout the academic years of 2020/2021 and 2021/2022 as part of a compulsory module of inorganic and general chemistry study at the University of East Anglia (UK). The School of Chemistry is a dual-intensive (research and teaching) department. For both cohorts we structured our online activity as a 1.5 h remote synchronous session composed of three parts: (i) an introductory briefing, (ii) the EEA, and (iii) a debriefing session with an opportunity for reflection. Throughout the activity, student interactions were facilitated using Microsoft Teams[50] breakout rooms. A pretest/post-test design was employed (Figure 3). Ethical approval was obtained for the evaluative aspect of the research study, and informed consent was obtained from all participants. Participants were randomly assigned to one of two groups to avoid bias and confounding variables:

1. **Experimental group 1.** Participants in this group completed the EEA containing 2D drawings of transition-metal complexes. This group was treated as the control condition.
2. **Experimental group 2.** Participants in this group completed the EEA containing embedded image targets

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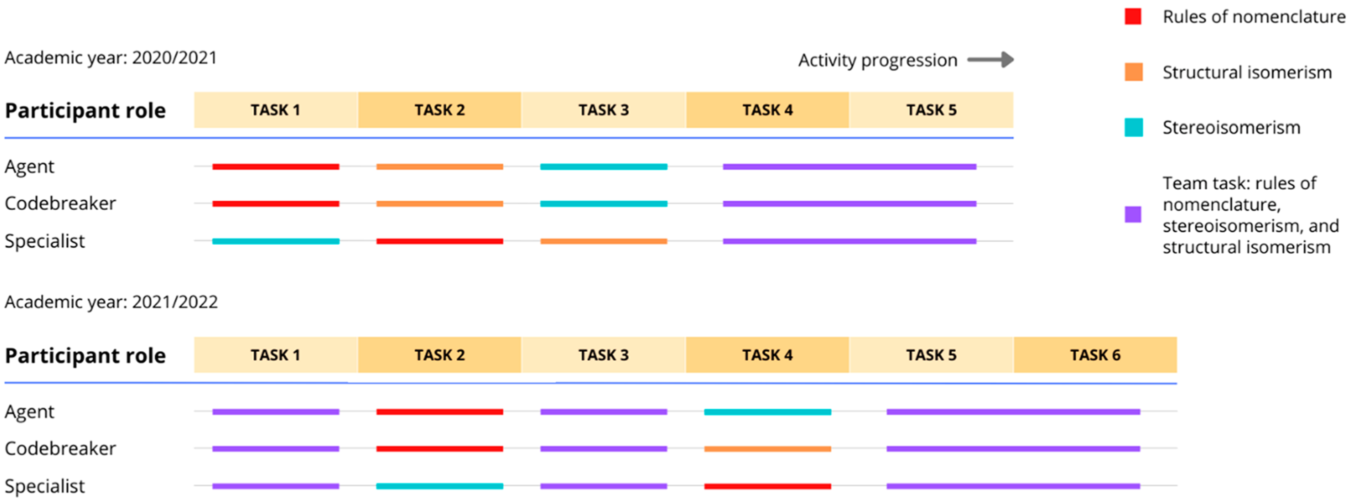

Figure 4. Sequence of tasks in the two iterations of our EEA and their relation to each of the learning objectives.

for generating three-dimensional (3D) virtual transition-metal complexes.

In preparation for this activity, a synchronous teaching session was conducted with the student cohort. Participants were assigned to one condition, either the control or AR EEA, to eliminate carryover effects.

Research Questions

This study attempts to explore how an EEA designed to support the needs of autonomy, competency, and relatedness affects students' motivation, and their understanding of stereochemistry concepts. The research questions investigated were as follows:

Research Question 1. Do students who participate in the AR-supported EEA perform better on the ITMC test instrument compared to those who participate in the control EEA?

Research Question 2. Are there significant differences between the AR and control groups regarding reported intrinsic motivation?

Research Question 3. What are the students' perceptions of the EEA as a learning experience?

■ EDUCATION ESCAPE ACTIVITY DESIGN

The design aspects for each iteration (Figure 4) of the EEA were informed by the psychological concepts of motivation and how elements of GBL can be implemented to ensure supports of competency, autonomy, and relatedness.

Students of autonomy-supportive teachers have demonstrated greater learning outcomes,[51] are more intrinsically motivated, and report higher perceived competence and internalization of learning activities.[52] We sought to actively support autonomy by providing a limited number of difficulty and exploration options. This was to avoid placing participants in a dilemma by offering too many choices.

Further, we supported competency by integrating challenging, but achievable, tasks designed to the skill level of the players. On completion of a task, we integrated feedback mechanisms to positively inform players regarding their progress. Guidance on the stereochemistry principles covered was provided through the provision of support pages. These can be accessed by players throughout tasks to ensure that the challenge remains perceived as achievable. The focus was to clarify, and organize, content based on the knowledge and skills required to achieve the learning objectives. By the end of the EEA, the student will be able to

1. **Demonstrate** application of the rules of nomenclature to **create** the name of a transition-metal complex (in line with IUPAC recommendations).[53]
2. **Differentiate** stereoisomers of different transition-metal complexes.
3. **Differentiate** structural isomers of different transition-metal complexes.

Throughout the activity, we attempted to facilitate social interaction, while eliminating factors that hinder the interactivity between users, to support their feelings of relatedness. When individuals feel they belong to a group, their need for relatedness is satisfied.[54] To accommodate this, Microsoft Teams breakout rooms were constructed for each participating group of three players, to encourage peer-to-peer discussion. Team-based tasks requiring contribution from multiple individuals were developed to foster collaboration.

In addition, our study will attempt to address previously reported limitations of EEAs. First, facilitating a physical EEA with large cohorts of students is difficult to achieve.[55,56] The use of a digital EEA is not dictated by this constraint and allows hosting of large concurrent player bases. This is an approach better suited to large student cohorts typical of a university setting. Our EEA was developed as a web browser experience. Browser-based games are technologically undemanding, easy to modify, and very accessible.

We also sought to evaluate the individual competency of each player, in line with the learning objectives, within each participant group. This is an extension of previously utilized evaluation metrics, such as completion rate, commonly used as an indication of competency among team members. To accomplish this, we introduced player roles, each with distinct subnarratives and tasks that contribute to the team goal of completing the activity. It is noteworthy that the roles do not require any distinct prerequisite skillsets in relation to the other two roles. They were distinct in terms of narrative but covered the same underlying stereochemistry concepts. For example, the Agent role requires a student to apply principles of stereoisomerism to decrypt intel, whereas the Specialist will apply the same principles of stereoisomerism to repair a reactor. Regardless of the role picked, each team member would encounter independent tasks as well as collaborative team tasks,

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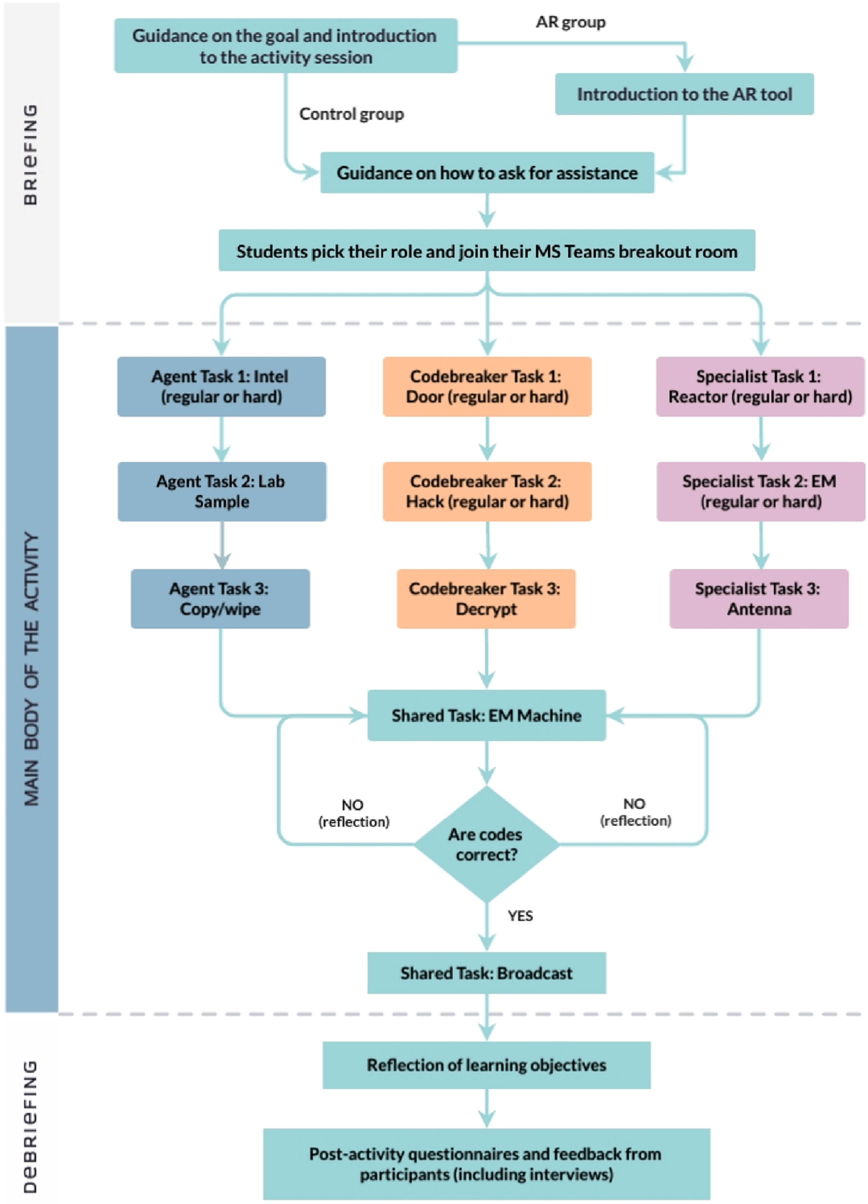

Figure 5. Process flow of our first iteration of the digital EEA, utilized during academic year 2020/2021.

designed to promote proficiency around the topics of inorganic stereochemistry. The narrative used within this iteration of our EEA was an extension of our previous study, which aimed to collect qualitative data pertaining to students' experiences in this learning environment.[21] The challenge thus evolved to constructing an AR-supported digital experience that incorporated the key competencies or learning objectives. The effectiveness of the EEA was examined using a mixed methods approach. Quantitative data regarding students' learning gains and measures of motivation were captured, alongside qualitative data pertaining to students' experiences.

Once each participating member has chosen their respective role within the EEA learning environment, the team is redirected toward a facility map, which acts as a hub for the tasks that require completion. The process flow for the first iteration of our digital activity is shown in Figure 5. Initially, most areas within the facility are inaccessible, but subsequent areas can be unlocked through completion of both individual and team-based (shared) tasks. Shared tasks are available immediately but require information from the role-specific tasks to complete. After the 2020/2021 cohort had experienced our EEA, design changes were made based upon discussion points identified during thematic analysis (which are outlined under the results section). The second iteration of our digital EEA contained the same tasks but with a modified process flow, shown in Figure 6. For example, Agent task 2 and Specialist task 3 were changed from role-specific tasks to team-based tasks. Furthermore, Codebreaker task 3 replaced Agent task 3. This was done to improve the balance of shared tasks to role-specific tasks.

■ ANALYSIS OF EEA PERFORMANCE AND ITMC SCORES

Table 1 displays the descriptive statistics concerning the ITMC test scores achieved by participants prior, and in response to, completing our EEA. Across both iterations, 51 students completed the ITMC at the pretest stage and 40 students at the post-test stage. Of these responses, 25 students completed

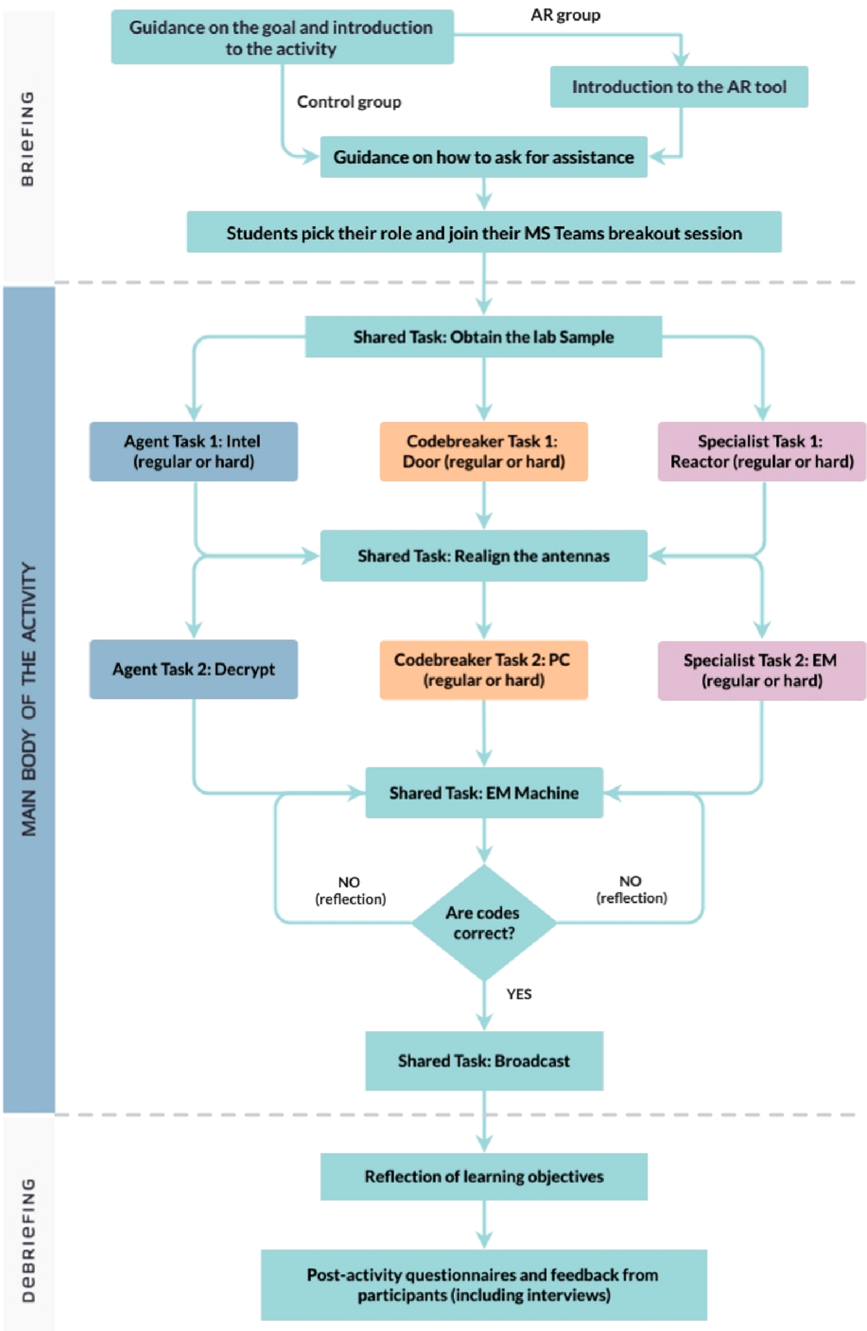

Figure 6. Process flow of our second iteration of the digital EEA, utilized during academic year 2021/2022.

Table 1. Relative Means and Standard Deviations for ITMC Scores

ITMC Test Instrument Score 0 (low) to 100 (high)	Control Group Mean (SD)	AR Group Mean (SD)
Pretest stage	53.00 (15.67)	43.33 (16.76)
Post-test stage	79.00 (16.63)	75.33 (20.31)

the instrument at both pre- and poststage stages. Following data collection, the Shapiro-Wilk test was used to check for the existence of normality. Although other methods for normality testing exist, Shapiro-Wilk has more power to detect the nonnormality on smaller samples sizes.[57] The data were found to be normally distributed at both pretest and post-test stages. In addition, Bartlett's test was conducted, verifying that the assumption of equal variances was true.

Intergroup comparisons were conducted using the independent samples t test. No significant differences were observed in the pretest mean scores, $t(23) = 1.449$, $p = 0.161$, or the post-test means obtained, $t(23) = 0.474$, $p = 0.640$. Analysis of scores on the ITMC instrument show neither group performing statistically better than the other on individual items. We hypothesized that the visualization affordance provided by AR would assist participants when answering items concerning stereoisomerism, although this was not observed, $t(23) = 1.389$, $p = 0.178$. To measure intragroup performance on the ITMC, we utilized the paired samples t test. We found significant improvements in ITMC test performance for both the control group, $t(9) = 3.621$, $p < 0.01$ and the AR group, $t(14) = 4.262$, $p < 0.01$.

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Normalized change calculations (Figure 7) were conducted as a measure of the learning gain between the pre- and post-test

$$c = \begin{cases} \dfrac{post - pre}{100 - pre} & post > pre \\ drop & post = pre = 100 = 0 \\ 0 & post = pre \\ \dfrac{post - pre}{pre} & post < pre \end{cases}$$

Figure 7. Normalized change calculations as outlined by Marx & Cummings.[60]

stages. The higher the normalized change, the greater the learning gain. For this study, the ranges defined by Hake[58] for normalized gain were adopted: low ($c < 0.3$), medium ($0.3 \leq c \leq 0.7$), and high ($0.7 \leq c$). The c values calculated were 0.44 for the AR group and 0.50 for the control group. To account for the variance in individual scores, we employed measures of effect size (Cohen's d) to compare how substantially different the groups were in terms of learning gain. The suggested values for effect size were employed: small (0.2), medium (0.5), and large (0.8).[59] The calculated effect size was 0.14, meaning that the difference between the two groups was less than 0.2 standard deviations.

A crucial component of developing research instruments is establishing reliability, thus providing users with information regarding the quality of items. Hence, to better understand item and scale difficulty and discrimination, we applied the concepts and analytical procedures of Classical Test Theory (CTT) and Item Response Theory (IRT). The extreme group method was used to calculate discrimination with groups partitioned by the top and bottom 27%.[61] A two-parameter logistic model (2PL) was employed.[62] Orlando and Thissen's S-χ^2 item-fit statistics, plus computed values of Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC) fit statistics (Table 2),[63] did not show an improved model fit to our data on addition of the pseudoguessing parameter (3PL).

Table 2. Model Level Fit Comparison for the 2PL and 3PL Models for This Study[a]

Model	Log-likelihood	AIC	BIC
2PL	−187.51	407.02	434.44
3PL	−185.43	418.86	459.99

[a]For the two statistics (AIC and BIC), a lower value indicates a better model fit to the data.

Items on the scale displayed good discrimination, constituting reasonable evidence that each item's score is positively related to the overall proficiency represented by performance on this instrument. Items 1 and 6 were considered the easiest items, generally at the lower estimate of individuals' ability. This is represented by the item-characteristic curves (ICCs) generated from our 2PL model. The inflection points of items 1 and 6 lie at an ability lower than −4. As such, we have omitted them from the item characteristic curves shown in Figure 8.

We employed Differential Item Functioning (DIF) to see if students of equal ability, but from different groups, have unequal probability to respond correctly to the items on the ITMC instrument. This is because DIF items can lead to biased

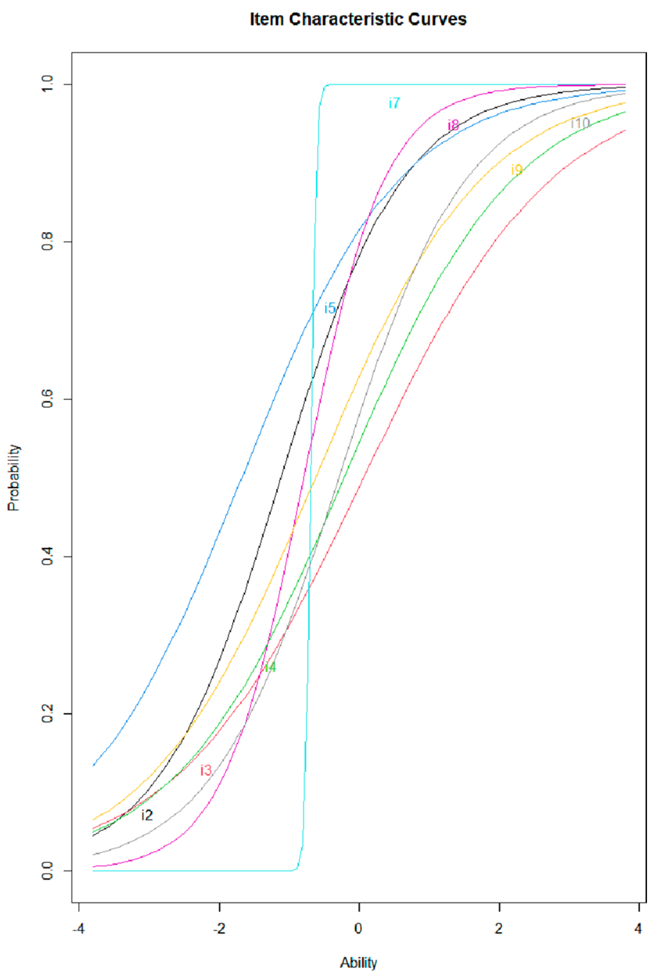

Figure 8. ICCs for items on the ITMC, generated using a 2PL model, excluding items 1 and 6.

measurement of ability.[64] Raju Signed Area method, detection thresholds: −1.96 and 1.96, significance level: 0.05 was employed. No items were detected as DIF items.

ANALYSIS OF IMI RESPONSES

We present the descriptive statistics pertaining to student responses on the IMI in Table 3. The authors of the original

Table 3. Results from the IMI Presented as Median[a]

IMI Subscale (7-point Likert scale)	Control Group (n = 38)	AR Group (n = 40)	Asymp Sig (2-tailed)	α
Interest/Enjoyment	5.14 (1.39)	5.00 (2.21)	0.766	0.909
Perceived Competence	4.00 (1.87)	3.75 (2.67)	0.306	0.943
Perceived Choice	4.57(1.57)	4.93(2.46)	0.714	0.869
Relatedness	4.94 (1.44)	5.00 (1.38)	0.715	0.748

[a]Interquartile range.

scale encourage adaption of items for use in different populations and specific activities.[47] The internal consistency of the instrument's subscales was established through calculation of Cronbach's alpha. The computed values are indicative of good internal consistency. Item deletion procedures suggest a higher alpha-if-deleted value for one item on the relatedness scale: (*item 25: I'd really prefer not to interact with this person in*

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the future). No item on any of the other three subscales demonstrated a higher alpha-if-deleted value.

Intergroup comparisons for each of the IMI subscales were conducted using the Mann−Whitney U test, a non-parametric test for ordinal data. The calculated asymptotic significances show that self-report measures of intrinsic motivation from participants in the AR group were not significantly different to those reported by the control group.

In addition, Spearman's correlations were conducted to explore the relationships between the constructs reported by each subscale of the IMI and the ITMC instrument (Table 4).

Table 4. Spearman's Correlations Conducted between IMI Subscales, and between IMI Subscales and the ITMC Test Instrument

	r_s			
Measure	Interest/ Enjoyment	Perceived Competence	Perceived Choice	Relatedness
Interest/ Enjoyment	1.000	0.698[b]	0.49[b]	0.028
Perceived Competence	0.698[b]	1.000	0.388[a]	0.091
Perceived Choice	0.489[b]	0.38[a]	1.000	0.189
Relatedness	0.028	0.091	0.189	1.000
ITMC total score	0.163	0.016	0.001	−0.070

[a]Correlation is significant at the 0.05 level (2-tailed). [b]Correlation is significant at the 0.01 level (2-tailed).

The interest/enjoyment subscale was strongly correlated with the perceived choice subscale and moderately correlated with the perceived competence subscale at the $p = 0.01$ level. This agrees with the hypothesis that perceived choice and perceived competence are positive predictors of measures of intrinsic motivation, considered to be assessed by the interest/enjoyment subscale. The perceived choice subscale was moderately correlated with the perceived competence subscale at the $p = 0.05$ level. The relatedness subscale did not display significant correlation with any of the three other IMI subscales. No significant correlations were observed between ITMC test scores and the four endorsed IMI subscales.

■ ANALYSIS OF QUALITATIVE DATA

We recruited seven students in total, from both experimental groups, to participate in semistructured interviews. The interview schedule covered four topic areas: (i) perception and satisfaction in response to attempting the EEA, (ii) interest and experience with games, (iii) value and usefulness of the EEA, and (iv) activity pressure and effort.

Qualitative analysis of the participant interviews was completed through latent thematic analysis using the approach of Braun & Clarke.[65] Data were recorded and transcribed verbatim, prior to being subjected to analysis for commonly occurring themes. The initial broad themes were constructed based on frequency and similarity of responses. Redundancy was eliminated, and closely related major themes were merged. In this paper we focus on three predominant themes found in student discussions: application of the subject content, affective and motivational factors, and evolving the activity.

We sought to ensure reliability in our analysis using two measures: (i) negotiated agreement and (ii) Krippendorff's alpha. Two of the authors independently coded the full set of interview transcripts and then negotiated how they applied the codes. Differences were discussed, and where there was a consistent disagreement, a common approach was agreed. The negotiated codebook employed is shown in Appendix A. Krippendorff's alpha is a commonly used chance-corrected reliability measure that avoids many of the limitations described for Cohen's kappa, such as its suitability to smaller samples sizes.[66] Krippendorff's alpha has ranges between −1.00 and 1.00, with positive values indicating agreement beyond chance. Values above 0.66 are acceptable for tentative conclusions.[66] The Krippendorff's alpha calculated for this study was 0.84.

Application of the Subject Content

All participants expressed views on the difficulty of the EEA in terms of both the game mechanics and the embedded chemistry content. Supporting the need for competency, students could attempt the same tasks at different levels of difficulty. Many students stated that the difficulty of the activity was suited to their level of chemistry experience, supporting the need for competency. *"I don't think it was easy, but it wasn't too hard either. I think it was the right amount of challenging."* (Interviewee G). Of all participants who attempted the activity, 42% of those selecting the specialist role attempted hard difficulty challenges. Further, 45% of codebreakers and 39% of agents also attempted the hard difficulty challenges. Participants articulated that, to improve, *"...it needs to be challenging, at least to a certain extent, for it to change you in a better way..."* (interviewee F).

Within this theme, we can identify different aspects relevant to learning. Participants stated that design aspects such as support pages "reinforced" the learning content throughout the activity. Responses suggest students found the activity to be a meaningful learning experience, *"I got something out of it. When I did the test, I got 8 out of 10, and I don't think I would have if I hadn't done the activity. It reinforces a lot of things."* (Interviewee B). This supports our collected quantitative data. Paired sample *t* tests and normalized change calculations demonstrated significant intragroup improvement on our ITMC test instrument prior to, and after, the activity (Table 1 and Figure 7). Within our discussions, students demonstrated reflection, *"I realized where I needed to go back and look..."*, (interviewee E), and stated that the opportunity to apply taught content promoted deeper understanding of the material.

"It got me to read those notes again, to facilitate answering these questions, and I thought that was really reinforcing." (Interviewee G).

"I sit in lectures thinking I understand the context of the chemistry at the time but having to use it in a different way immediately afterwards helped reinforce it." (Interviewee A).

Our quantitative data indicate that the introduction of ChemFord into our EEA did not result in significantly higher post-test results on the ITMC test instrument, compared to the control EEA condition. We believed that ChemFord would assist cognitive processing associated with mental visualization, thus supporting students, for example, when approaching problems regarding the spatial relations of ligands in transition-metal complexes. However, variables such as intrinsic and extraneous cognitive load were not measured as part of this study. Conducting an ANCOVA shows no significant differences between the different aspects of the ITMC test instrument: rules of nomenclature, $F(1,24) = 0.516$, $p = 0.480$, stereoisomerism, $F(1,24) = 0.452$, $p = 0.508$, and structural isomerism, $F(1,24) = 0.071$, $p = 0.792$.

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Affective and Motivational Factors

In their accounts, participants highlighted their experiences of the EEA. During a challenging period of transition to online learning, students positively perceived the integration of our online synchronous activity. *"I really enjoyed it. I thought the escape room was really well made. I thought it was really good fun."* (Interviewee A). This was supported by higher reported measures of interest/engagement on the IMI survey. When asked, students expressed a desire to repeat this style of activity in future modules throughout their degree. *"I would definitely want to see it happen again, not just in this module, or in this course, I'm sure it's going to be beneficial for other courses as well."* (Interviewee F). Participants frequently used terms such as "engaging", "satisfying", and "useful" to describe the activity.

"I'd say it was a good use of time to consolidate things and correct some misconceptions that I had beforehand." (Interviewee G).

In contrast, negative student feelings were also noted. An absence of direct instruction, due to the nature of the activity, left some students feeling initially overwhelmed. *"There was definitely some stress and anxiety at the start"* (interviewee D). In addition, students expressed that they felt the time pressure. However, most students stated that *"...when we started bouncing ideas off each other on how to progress, that anxiety started to go away..."* (interviewee G) and that it became *"...more enjoyable than stressful..."* (interviewee C). On supporting the need of relatedness, students positively responded to collaboratively working given the limited interaction with their peers.

"It was nice to have to work with someone from the course. Because this year, I haven't really met many people from the course." (Interviewee F).

All participants stated that they believed the EEA worked as an effective team activity. Students also expressed support toward their peers, *"...when a person in the team competed their part...I don't know if proud is the right word?"* (Interviewee C). However, challenges regarding the facilitation of the team interactivity were raised.

"If possible, [do the activity] in person next year. And that's always better, because it's so much easier to get past that initial awkwardness in person than it is online." (Interviewee G).

"I would say, I think if I had been in a group where I didn't know anybody, I probably would have felt anxious about meeting them and having to speak." (Interviewee A).

Evidence of extrinsic motivation was apparent, *"...the other two members had taken the effort to show up. They needed codes from me to complete it..."* (interviewee A), with another participant exclaiming that *"...trying to find that intrinsic motivation is quite challenging for me..."* (interviewee C). To explore the topic of motivation, we asked participants about their gaming experience outside of an educational setting. Most students stated that they "play a lot of video games", but with no preference for competitive or cooperative play.

Following this, our discussions led on to what motivated participants to continue playing a game once the difficulty surpasses their current ability. Responses typically fell into: (i) competitiveness, *"I think it appeals to my competitiveness"*, (interviewee A) and (ii) self-improvement, *"Improving myself in order to feel like I'm good enough."* (Interviewee E). To understand if this translated to our EEA, we posed a similar discussion with our participants. Self-improvement and the contribution of the activity to participants' learning were the primary responses. *"For me, cracking the safe and completing the puzzle is a reward in itself. I want to know that I can do it."* (Interviewee B).

Between-groups, the introduction of AR did not result in greater measures on any of the four subscales of the IMI. Our qualitative discussions show evidence of extrinsic motivation, more specifically the process of identification. This is represented by students showing conscious valuing of the activity and personal importance. The process of internalization toward intrinsic motivation is also evident, with students stating their interest, enjoyment, and inherent satisfaction of the learning experience. However, it is noteworthy that these perceptions were present in both experimental groups, not just those students utilizing the AR technology. We believed that introducing ChemFord as an educational tool would help to support the psychological need of competency. Yet, measures of perceived competence between the two groups were not significantly different, $t(76) = 1.070$, $p = 0.288$, but were shown to be positively correlated with intrinsic motivation. Again, the difficulty of the tasks within the EEA were perceived as sufficiently difficulty by both groups. As such, the introduction of AR may not have provided the cognitive benefits we perceived it would in this instance. Furthermore, AR may have thwarted the need for autonomy through requiring the user to interact with ChemFord specifically. However, perceived choice was not significantly different between groups, $t(76) = 0.267$, $p = 0.790$. Lastly, qualitative data did not provide any evidence of amotivation or external regulation.

Evolving the Activity

As a formative session, engagement in the EEA was a choice by our participants. Therefore, an important consideration is to identify how to provide supportive strategies to ensure students will be more likely to experience psychological need satisfaction. SDT lends itself well to intervention work, as throughout the iterative design process, we can capitalize on the opportunity to explore whether improving the levels of need support in our EEA positively impacts levels of intrinsic motivation and the targeted learning outcomes.

Several discussion points were captured for consideration between our first and second iterations. First, participant teams will commonly be composed of students of differing chemistry experience. As such, instances arose with individual tasks, where players were completing them at different rates. This resulted in the generation of "dead zones" where players were potentially inactive while awaiting further information from their teammates.

"I finished my tasks before the other two did. So, all I was doing was it was helping my teammates do their tasks. If I'm being honest, I sat there thinking, 'okay, I need something to do whilst I'm waiting'". (Interviewee A).

This is an example of a relatedness thwarting strategy, exhibited by an active dislike toward an aspect of our learning environment. To support relatedness and inclusion of team members, the second iteration of our EEA was designed to begin with a team task as well as having a lower emphasis on individual tasks. This design idea was suggested by students throughout our qualitative data collection, *"100%. I think using a team task at the start to help people bond straight away would be a good idea."* (Interviewee D). While facilitating our EEA activity in academic year 2021/2022, it was apparent that greater levels of peer-to-peer discussion were taking place as a result of this design change. A greater measure of relatedness on the IMI survey was reported during the second iteration (5.44), but this was not statistically significant when compared to the first iteration.

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Balancing the Game-Based Learning mechanics with the chemistry content of a task was also commented upon, "...there were a couple of points where, I think, individually, we were a bit stuck to the premise of a couple of the tasks, and exactly what it wanted from us, rather than the chemistry", (interviewee A). To avoid thwarting the need for competency, we reviewed data from two sources to inform whether tasks required revision between iterations of our activity: (i) qualitative feedback from participant interviews and (ii) quantitative data gathered from tracking statistics. Where participants explicitly stated that a task was difficult, or tracking statistics displayed minimal player progress, changes were made to ensure tasks remained achievable. This also avoids the game mechanics confounding with the potential benefits of the AR technology.

STUDY LIMITATIONS

Some limitations of this study must be acknowledged. First, a major limitation is the relatively small sample size that the data analysis was based upon. The sample size was the result of modest enrollment compounded by participant disengagement between the pre- and post-test stages. As such, it is not possible to generalize our findings based on the sample size of this study. Second, following the adoption of online learning in response to the COVID-19 pandemic, we did not have the opportunity to observe students' interactions with the AR technology when participants were completing our EEA. It would be interesting to understand how IMI measurements for students interacting with ChemFord alone compare to those of students engaging with our AR-supported EEA. Furthermore, we must acknowledge the possibility of self-selection bias from participants.[67] Students who volunteer for interviews may be different from the rest of the population regarding their communication ability or reasoning levels. Lastly, we were unable to evaluate the learning gains of students who did not participate in either the control or AR condition (i.e., no intervention). This would allow us to understand if a student who completed the ITMC test instrument twice displayed significant improvements in their score, as a result of reflection between the pre- and post-test stages.

CONCLUSION

There is little doubt that motivation can be influential on the degree to which individuals engage with learning experiences. This study illustrates how the design of an AR-embedded EEA to support motivation can be employed. Throughout both iterations of our activity, a positive opinion ran throughout our participants' discussions. The design of our EEA provides one approach to implementing this style of learning activity, in a way that supports virtual presence, and is scalable to large student cohorts. As previously hypothesized, reported measures of competency were seen as a positive predictor of intrinsic motivation. However, in this study, this was not observed to be a positive predictor of academic performance.

We have provided initial reliability evidence for our stereochemistry test instrument, developed for the purposes of this study, using the approaches of CTT and IRT (2PL model). Items 1 and 6 were shown to be the easiest items on the scale. Differential Item Functioning showed no biased measurement of ability between groups when using the Raju Signed Area method.

With reference to our research questions, the introduction of AR, over and above the EEA, did not result in any significant differences in reported intrinsic motivation or post-test scores on our stereochemistry instrument. Significant intragroup academic improvement was also observed in both experimental groups. Collected qualitative data suggest that participants found the activity to be useful and engaging. Through students' discussions, we have provided evidence of how design aspects of the EEA support the psychological need satisfaction outlined by SDT. This indicates how future evolution of the activity can prevent thwarting these needs. Future research could look at how technological aspects, such as immersion, and psychological consequences of immersion, such as presence, are impacted by the utilization of AR in physical and digital escape activities and how this may impact academic performance.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00428.

- A copy of our interview schedule. In addition, we have also supplied a copy of our negotiated codebook used throughout our qualitative data analysis (PDF)
- A copy of the ITMC test instrument (DOCX)
- Details of the analysis of the ITMC test instrument (PDF)
- A copy of our interview schedule. In addition, we have also supplied a copy of our negotiated codebook used throughout our qualitative data analysis (DOCX)
- A copy of the ITMC test instrument (PDF)
- Evidence of the reliability fit statistics and DIF measurements from our IRT modeling (DOCX)

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Notes

The authors declare no competing financial interest.

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REFERENCES

(1) Wentzel, K. *Motivating students to learn*, 5th ed.; Routledge, 2020.
(2) Holme, T. Introduction To The Journal Of Chemical Education Special Issue On Insights Gained While Teaching Chemistry In The Time Of COVID-19. *J. Chem. Educ.* **2020**, 97 (9), 2375–2377.

(3) Tercanli, H.; Martina, R.; Wakkee, A.; Gomes, I.; Meireles, I.; Mortensen, A.; Zinovyeva, A.; Rodríguez-Díaz, A.; Gutiérrez-Pérez, D.; Ferreira Dias, M.; Wakkee, I.; Amorim, M.; Madaleno, M.; Magueta, D.; Vieira, E.; Veloso, C.; Figueiredo, C.; Mortensen, A.; Zinovyeva, A.; Rivera Trigueros, I. *Educational Escape Rooms in Practice: Research, Experiences and Recommendations;* UA Editora, 2021. DOI: 10.34624/rpxk-hc61.

(4) SCRAP. A Party of Riddles, Puzzles, Curry and Beer (Translation), 2007. Available online at https://realdgame.jp/event/nazotokinoutage.html.

(5) Magson, S.; Macpherson, S. All escape games and best escape rooms in the United Kingdom on worldofescapes.co.uk. https://worldofescapes.co.uk/ (accessed 2022-03-01).

(6) Lopez-Pernas, S.; Gordillo, A.; Barra, E.; Quemada, J. Comparing Face-To-Face And Remote Educational Escape Rooms For Learning Programming. *IEEE Access* **2021**, *9*, 59270−59285.

(7) Avargil, S.; Shwartz, G.; Zemel, Y. Educational Escape Room: Break Dalton's Code And Escape! *J. Chem. Educ.* **2021**, *98* (7), 2313−2322.

(8) Piñero Charlo, J.; Ortega García, P.; Román García, S. Formative Potential Of The Development And Assessment Of An Educational Escape Room Designed To Integrate Music-Mathematical Knowledge. *Education Sciences* **2021**, *11* (3), 131.

(9) Zaug, P.; Gros, C.; Wagner, D.; Pilavyan, E.; Meyer, F.; Offner, D.; Strub, M. Development Of An Innovative Educational Escape Game To Promote Teamwork In Dentistry. *Eur. J. Dent. Educ.* **2021**.116122

(10) Abdollahi, A.; Masento, N.; Vepsäläinen, H.; Mijal, M.; Gromadzka, M.; Fogelholm, M. Investigating The Effectiveness Of An Educational Escape Game For Increasing Nutrition-Related Knowledge In Young Adolescents: A Pilot Study. *Frontiers in Nutrition* **2021**, *8*. DOI: 10.3389/fnut.2021.674404

(11) Lopez-Pernas, S.; Gordillo, A.; Barra, E.; Quemada, J. Escapp: A Web Platform For Conducting Educational Escape Rooms. *IEEE Access* **2021**, *9*, 38062−38077.

(12) Ross, R.; de Souza-Daw, A. Educational Escape Rooms As An Active Learning Tool For Teaching *Telecommunications Engineering. Telecom* **2021**, *2* (2), 155−166.

(13) Vidergor, H. Effects Of Digital Escape Room On Gameful Experience, Collaboration, And Motivation Of Elementary School Students. *Computers & Education* **2021**, *166*, 104156.

(14) Oestreich, J.; Hunt, B.; Cain, J. Grant Deadline: An Escape Room To Simulate Grant Submissions. *Currents in Pharmacy Teaching and Learning* **2021**, *13*, 848.

(15) Vergne, M.; Simmons, J.; Bowen, R. Escape The Lab: An Interactive Escape-Room Game As A Laboratory Experiment. *J. Chem. Educ.* **2019**, *96* (5), 985−991.

(16) Vergne, M.; Smith, J.; Bowen, R. Escape The (Remote) Classroom: An Online Escape Room For Remote Learning. *J. Chem. Educ.* **2020**, *97* (9), 2845−2848.

(17) Peleg, R.; Yayon, M.; Katchevich, D.; Moria-Shipony, M.; Blonder, R. A Lab-Based Chemical Escape Room: Educational, Mobile, And Fun! *J. Chem. Educ.* **2019**, *96* (5), 955−960.

(18) Janonis, A.; Kiudys, E.; Girdžiūna, M.; Blažauskas, T.; Paulauskas, L.; Andrejevas, A. Escape The Lab: Chemical Experiments In Virtual Reality. *Communications in Computer and Information Science* **2020**, *1283*, 273−282.

(19) Ferreiro-González, M.; Amores-Arrocha, A.; Espada-Bellido, E.; Aliaño-Gonzalez, M.; Vázquez-Espinosa, M.; González-de-Peredo, A.; Sancho-Galán, P.; Álvarez-Saura, J.; Barbero, G.; Cejudo-Bastante, C. Escape Classroom: Can You Solve A Crime Using The Analytical Process? *J. Chem. Educ.* **2019**, *96* (2), 267−273.

(20) Clapson, M.; Gilbert, B.; Mozol, V.; Schechtel, S.; Tran, J.; White, S. Chemescape: Educational Battle Box Puzzle Activities For Engaging Outreach And Active Learning In General Chemistry. *J. Chem. Educ.* **2020**, *97* (1), 125−131.

(21) Elford, D.; Lancaster, S.; Jones, G. Stereoisomers, Not Stereo Enigmas: A Stereochemistry Escape Activity Incorporating Augmented And Immersive Virtual Reality. *J. Chem. Educ.* **2021**, *98* (5), 1691−1704.

(22) Ang, J.; Ng, Y.; Liew, R. Physical And Digital Educational Escape Room For Teaching Chemical Bonding. *J. Chem. Educ.* **2020**, *97* (9), 2849−2856.

(23) Estudante, A.; Dietrich, N. Using Augmented Reality To Stimulate Students And Diffuse Escape Game Activities To Larger Audiences. *J. Chem. Educ.* **2020**, *97* (5), 1368−1374.

(24) Yayon, M.; Rap, S.; Adler, V.; Haimovich, I.; Levy, H.; Blonder, R. Do-It-Yourself: Creating And Implementing A Periodic Table Of The Elements Chemical Escape Room. *J. Chem. Educ.* **2020**, *97* (1), 132−136.

(25) Quintero, J.; Baldiris, S.; Rubira, R.; Cerón, J.; Velez, G. Augmented Reality In Educational Inclusion. A Systematic Review On The Last Decade. *Frontiers in Psychology* **2019**, *10*. DOI: 10.3389/fpsyg.2019.01835

(26) Milgram, P.; Takemura, H.; Utsumi, A.; Kishino, F. Augmented Reality: A Class Of Displays On The Reality-Virtuality Continuum. *Telemanipulator and Telepresence Technologies* 1995.*2351* DOI: 10.1117/12.197321

(27) Abdinejad, M.; Talaie, B.; Qorbani, H.; Dalili, S. Student Perceptions Using Augmented Reality And 3D Visualization Technologies In Chemistry Education. *Journal of Science Education and Technology* **2021**, *30* (1), 87−96.

(28) Nechypurenko, P. P.; Stoliarenko, V.; Starova, T.; Selivanova, T.; Markova, O. M.; Modlo, Y.; Shmeltser, E. Development and Implementation of Educational Resources in Chemistry with Elements of Augmented Reality; 2020. DOI: 10.31812/123456789/3751

(29) Woźniak, M.; Lewczuk, A.; Adamkiewicz, K.; Józiewicz, J.; Malaya, M.; Ladonski, P. ARchemist: Aiding Experimental Chemistry Education Using Augmented Reality Technology. *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, 2020. DOI: 10.1145/3334480.3381441

(30) Abdinejad, M.; Ferrag, C.; Qorbani, H.; Dalili, S. Developing A Simple And Cost-Effective Markerless Augmented Reality Tool For Chemistry Education. *J. Chem. Educ.* **2021**, *98* (5), 1783−1788.

(31) Aw, J.; Boellaard, K.; Tan, T.; Yap, J.; Loh, Y.; Colasson, B.; Blanc, É.; Lam, Y.; Fung, F. Interacting With Three-Dimensional Molecular Structures Using An Augmented Reality Mobile App. *J. Chem. Educ.* **2020**, *97* (10), 3877−3881.

(32) Estudante, A.; Dietrich, N. Using Augmented Reality To Stimulate Students And Diffuse Escape Game Activities To Larger Audiences. *J. Chem. Educ.* **2020**, *97* (5), 1368−1374.

(33) Wild, F.; Marshall, L.; Bernard, J.; White, E.; Twycross, J. UNBODY: A Poetry Escape Room In Augmented Reality. *Information* **2021**, *12* (8), 295.

(34) Vicari, C. Escape The Planet: Empowering Student Designers To Create A Science-Based Escape Room With Augmented Reality. *International Journal of Designs for Learning* **2020**, *11* (2), 80−95.

(35) Zeng, H.; He, X.; Pan, H. Implementation Of Escape Room System Based On Augmented Reality Involving Deep Convolutional Neural Network. *Virtual Reality* **2021**, *25* (3), 585−596.

(36) Burrows, A.; Holman, J.; Lancaster, S.; Parsons, A.; Overton, T.; Pilling, G.; Price, G. *Chemistry3: Introducing Inorganic, Organic and Physical Chemistry;* Oxford University Press, 2021.

(37) Hurley, Z. Thinking With Semiotic-Dialogism: Re-Orientating Augmented Reality And Visual Literacy. *Studies in Technology Enhanced Learning* **2022**. DOI: 10.21428/8c225f6e.4e1f8d49

(38) Ryan, R.; Deci, E. Intrinsic And Extrinsic Motivation From A Self-Determination Theory Perspective: Definitions, Theory, Practices, And Future Directions. *Contemporary Educational Psychology* **2020**, *61*, 101860.

(39) Reeve, J. A Self-Determination Theory Perspective On Student Engagement. *Handbook of Research on Student Engagement;* Springer, 2012; pp 149−172. DOI: 10.1007/978-1-4614-2018-7_7

(40) Kam, H.; Menard, P.; Ormond, D.; Crossler, R. Cultivating Cybersecurity Learning: An Integration Of Self-Determination And Flow. *Computers & Security* **2020**, *96*, 101875.

(41) Liu, W.; Wang, C.; Kee, Y.; Koh, C.; Lim, B.; Chua, L. College Students' Motivation And Learning Strategies Profiles And Academic

Achievement: A Self-Determination Theory Approach. *Educational Psychology* **2014**, *34* (3), 338−353.
(42) Huang, Y.; Backman, S.; Backman, K.; McGuire, F.; Moore, D. An Investigation Of Motivation And Experience In Virtual Learning Environments: A Self-Determination Theory. *Education and Information Technologies* **2019**, *24* (1), 591−611.
(43) Deci, E.; Ryan, R. *Intrinsic motivation and self-determination in human behavior;* Springer Science+Business Media: New York, 2014.
(44) Taylor, G.; Jungert, T.; Mageau, G.; Schattke, K.; Dedic, H.; Rosenfield, S.; Koestner, R. A Self-Determination Theory Approach To Predicting School Achievement Over Time: The Unique Role Of Intrinsic Motivation. *Contemporary Educational Psychology* **2014**, *39* (4), 342−358.
(45) Ryan, R.; Ryan, W.; Di Domenico, S.; Deci, E. The Nature And The Conditions Of Human Autonomy And Flourishing. In *The Oxford Handbook of Human Motivation;* Oxford University Press, 2019; pp 88−110.
(46) Proulx, J.; Romero, M.; Arnab, S. Learning Mechanics And Game Mechanics Under The Perspective Of Self-Determination Theory To Foster Motivation In Digital Game Based Learning. *Simulation & Gaming* **2017**, *48* (1), 81−97.
(47) Intrinsic Motivation Inventory (IMI) – https://selfdeterminationtheory.org/intrinsic-motivation-inventory/ (accessed 2022-03-01).
(48) McAuley, E.; Duncan, T.; Tammen, V. Psychometric Properties Of The Intrinsic Motivation Inventory In A Competitive Sport Setting: A Confirmatory Factor Analysis. *Research Quarterly for Exercise and Sport* **1989**, *60* (1), 48−58.
(49) Tsigilis, N.; Theodosiou, A. Temporal Stability Of The Intrinsic Motivation Inventory. *Percept Mot Skills* **2003**, *97* (1), 271−280.
(50) Video Conferencing, Meetings, Calling | Microsoft Teams. https://www.microsoft.com/en-us/microsoft-teams/group-chat-software (accessed 2022-06-30).
(51) Vallerand, R.; Fortier, M.; Guay, F. Self-Determination And Persistence In A Real-Life Setting: Toward A Motivational Model Of High School Dropout. *Journal of Personality and Social Psychology* **1997**, *72* (5), 1161−1176.
(52) Hardre, P.; Reeve, J. A Motivational Model Of Rural Students' Intentions To Persist In, Versus Drop Out Of, High School. *Journal of Educational Psychology* **2003**, *95* (2), 347−356.
(53) Connelly, N. *Nomenclature of inorganic chemistry;* Royal Society of Chemistry: Cambridge, UK, 2005.
(54) Reeve, J.; Deci, E. L.; Ryan, R. M. Self-determination theory: A dialectical framework for understanding socio-cultural influences on student motivation. In McInerney, D. M., Van Etten, S., Eds.; *Big Theories Revisited;* Information Age Press, 2004; pp 31−60.
(55) Cain, J. Exploratory Implementation Of A Blended Format Escape Room In A Large Enrollment Pharmacy Management Class. *Currents in Pharmacy Teaching and Learning* **2019**, *11* (1), 44−50.
(56) Clarke, S.; Peel, D.; Arnab, S.; Morini, L.; Keegan, H.; Wood, O. Escaped: A Framework For Creating Educational Escape Rooms And Interactive Games To For Higher/Further Education. *Int. J. Serious Games* **2017**, *4* (3). DOI: 10.17083/ijsg.v4i3.180
(57) Gupta, A.; Mishra, P.; Pandey, C.; Singh, U.; Sahu, C.; Keshri, A. Descriptive Statistics And Normality Tests For Statistical Data. *Annals of Cardiac Anaesthesia* **2019**, *22* (1), 67.
(58) Hake, R. Interactive-Engagement Versus Traditional Methods: A Six-Thousand-Student Survey Of Mechanics Test Data For Introductory Physics Courses. *American Journal of Physics* **1998**, *66* (1), 64−74.
(59) Wassertheil, S.; Cohen, J. Statistical Power Analysis For The Behavioral Sciences. *Biometrics* **1970**, *26* (3), 588.
(60) Marx, J.; Cummings, K. Normalized Change. *American Journal of Physics* **2007**, *75* (1), 87−91.
(61) Preacher, K. Extreme Groups Designs. *Encyclopedia of Clinical Psychology* **2015**, 1−4.
(62) Stenbeck, M.; Hambleton, R.; Swaminathan, H.; Rogers, H. Fundamentals Of Item Response Theory. *Contemporary Sociology* **1992**, *21* (2), 289.
(63) Acquah, H. D. Comparison of Akaike information criterion (AIC) and Bayesian information criterion (BIC) in selection of an asymmetric price relationship. *Journal of development and agricultural economics* **2010**, *2*, 1−6.
(64) Lim, R.; Drasgow, F. Evaluation Of Two Methods For Estimating Item Response Theory Parameters When Assessing Differential Item Functioning. *Journal of Applied Psychology* **1990**, *75* (2), 164−174.
(65) Braun, V.; Clarke, V. Using Thematic Analysis In Psychology. *Qualitative Research in Psychology* **2006**, *3* (2), 77−101.
(66) Krippendorff, K. *Content analysis An Introduction to Its Methodology,* 4th ed.; SAGE, 2018.
(67) Heckman, J. J. Selection bias and self-selection. *In Econometrics* **1990**, 201−224.

https://doi.org/10.1021/acs.jchemed.2c00428
J. Chem. Educ. 2022, 99, 3406−3417