Tiako P.F. (ed) *Intelligent Computing and Consumer Support Applications*. Chronicle of Computing. OkIP

https://doi.org/10.55432/978-1-6692-0003-1_3

Assessing the Impact of Interactivity in the Cognitive Domain: A Noise Ratings Case Study

Flaithrí Neff, Patrick Duffy, Malachy Ronan

Technological University of the Shannon, Limerick, Ireland

ABSTRACT

The widescale implementation of Emergency Remote Teaching during the pandemic has normalized the use of blended and online learning-tools in third-level education. However, many of these digital tools are not designed to achieve specific learning objectives, leading to mixed results reported by instructors and students. Although such tools aim to make the educational experience an active one for students, there is limited empirical data on their effectiveness on knowledge-acquisition and learning. These issues are more pronounced in some disciplines compared to others, and in this paper, we present an assessment of a newly-developed interactive application relevant to music-technology - a discipline that is traditionally reliant on campus-based, in-studio experiences. In a user-study comparing a traditional approach and the use of this interactive application to present the topic 'Noise Ratings' to undergraduates, results show significant improvements on questions in the "Understand" and "Application" taxonomy levels between pre- and post-time intervals.

Keywords: Remote Teaching, Interactive Learning Application, Online Learning, Blended Learning, Noise Ratings, Bloom's Taxonomy, Cognitive Domain.

I. INTRODUCTION

March 12th 2020 signaled the Government of Ireland's issuance to close onsite education settings in an effort to respond to the country's rising COVID-19 cases. For most third-level institutions, this was facilitated by moving course content and delivery modes to online platforms exclusively, followed by a phased-in blended approach during the 2020/2021 academic year. Although obstacles and difficulties were plentiful (due in part to the abruptness of the onsite-to-remote pivot), it also demonstrated that online and blended learning-tools have a role to play in mainstream third-level education. However, with relatively little standardization and guidance in how these tools should be utilized to maximize learning outcomes, there is a need for more empirical data in how they perform on this basis (especially in discipline-specific contexts). Without these data, it remains difficult for application designers to compose tools that meet the appropriate learning metrics.

In this paper, we describe the design of an interactive application for presenting the topic of Noise Rating curves (NR curves) to music technology students, and the outcomes of a user-study comparing the use of this application to traditional modes of presentation. An analysis of results shows significant improvements when using the interactive app in "Understanding" and "Application" Bloom taxonomy levels between pre- and post-time intervals.

Future research will examine longitudinal outcomes of the application's use by students beyond their designated lab-sessions throughout the academic year. The authors also aim to build additional interactive applications to present complex acoustics-related topics to music-technology students. The intention will be to build on empirical data over time to gain a deeper understanding of the effectiveness and performance of interactive tools for learning domain-specific content.

II. BACKGROUND

A. NR Curves

NR curves were developed by the International Organization for Standardization (ISO) and introduced in standard ISO/R 1996:1971, now superseded by ISO 1996-2:2017 (currently in its 5-year review phase). They define the level of background noise present in an environment and report this using a single value. These NR values are generated by measuring noise levels across the frequency spectrum in 1:1 octave-bands, plotting these values to a graph, and identifying the highest value collected in each octave band. This value determines the NR curve number applicable to that frequency band. The highest recorded NR value is used to define the NR curve representing the audible background noise-level present in an environment.

Fig. 1 presents NR curves ranging from NR0 (background noise that is perceptually silent) to NR130 (background noise that will cause hearing damage). Although the curves shown in Fig. 1 increment by +10, data for higher-resolution increments (e.g. +5) are also available. Whilst NR values provide a simplified model of the noise present in an environment, they are frequently used to evaluate the impact of background noise on foreground sound-sources or to identify and monitor noise levels for public health and safety. This is because they more accurately represent the impact on listeners than unweighted SPL measures and they are context dependent. For example, background noise with an NR value greater than 30 but less than 35 is unlikely to impact on the functional activities of people working in a library, school, museum, or office. However, this level of background noise would have a negative effect on the functioning of recording studios (see bottom-right text in Fig. 2).

B. Presenting NR Curves to Learners

Delivering NR-curve content to undergraduate students presents several difficulties. Whilst NR-curves describe an auditory phenomenon, the tools used to explore the NR values are typically visual, such as graph-based tabular data (Engineering toolbox, 2003b), images, or calculators (Building

* Corresponding author E-mail: Flaithri.Neff@tus.ie

Presented at the 2022 OkIP International Conference on Learning and Technology in Education (CLTE) in Oklahoma City, OK, USA, and Online, on October 3-6, 2022

Calculators, 2019; Engineering toolbox, 2003a). Compounding this issue, two environments with the same NR value may sound completely different, thus increasing the cognitive load for the learner. Additionally, many students have little experience with applications such as Microsoft Excel to record numerical data, which adds further challenge to the task.

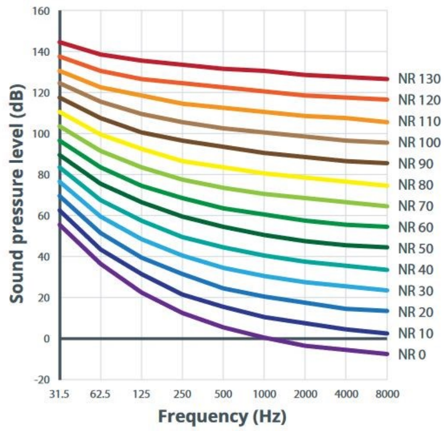

Fig. 1. A graph displaying NR curves from NR0 to NR130. (Acoustic Comfort, 2016)

III. Application Design

A. Background

A multimodal interactive application was developed to support students learning to compute NR-curves, referred to in this paper as MINR (Multimodal Interactive Noise Rating). Originally intended as a Web App running in a standard browser to support future scaling, the local server environment lacked a required backend component forcing the porting of MINR to another development environment. While this had no practical implications for the user-study presented in this paper, subsequent studies will use the web app to capture longitudinal data from students working on their personal computers. Therefore, it will be imperative that the server issue be rectified going forward and that the original development-environment reconstituted for future test phases.

B. App Development – MATLAB Version

The initial development environment comprised MathWorks MATLAB version R2021b, MathWorks App Designer for UI components, and Web App Compiler for final deployment (MathWorks, 2022a). A MATLAB application developed by Dring (2021), titled *Calculation of NR Curves*, was the basis for the rendered Web App intended for this user-study. The primary components incorporated from Dring were the NR calculations, the graph representation of NR curves, and GUI features. Dring's app was itself compiled on MATLAB version R2020b and kindly shared on the MATLAB Central File Exchange (MathWorks, 2022b).

The following alterations were made to Dring's original application in the authors' modified MATLAB version:

- The addition of a 31.5 Hz user input-box, including its underlying NR calculation, solved output, and graph representation.
- The deletion of an instruction box that was not functional to our user-study.
- The addition of a pink-noise audio calibration feature to standardize audio output across all participant headphones.
- The addition of a filtered pink-noise render of the user-input NR curve to serve as an auditory feedback feature to the represented visual graph.
- The addition of a sound-sample button to provide participants with contextual auditory feedback in relation to critical-listening environments and user-input NR curves. This sound sample combines the NR-derived filtered pink-noise with a quiet studio recording to depict background noise in a recording-studio context.
- The addition of a foundry-sample button to provide participants with contextual auditory feedback in relation to industrial environments and user-input NR curves. This foundry sample combines the NR-derived filtered pink-noise with a loud industrial recording to depict background noise in an industrial context.

C. App Development – Max Version

Given the host server lacked the MATLAB Web App Server to allow the compiled Web App to run on lab-machine browsers, the app was programmed using Max version 8.8.2 and exported as a standalone Max app (Cycling '74, 2022). This app retained all feature sets, both Dring's original GUI and graph layout, and the added audio feedback and graphic facilities mentioned in the authors' modified MATLAB app. The NR calculations and resultant filters in the Max version of MINR was designed to perform identically to the MATLAB render.

IV. Interacting with MINR – Max Version

A. NR Data used in Interactive NR Applications

The following section outlines how the Max version of MINR functions (see Fig. 2). Note that this description is directly applicable to the modified MATLAB version of MINR in terms of user-interaction and underlying NR calculations, and that the differences between these two versions are simply cosmetic. Also note that MINR (both the Max and the modified MATLAB versions) restrict maximum user-input values along NR70 instead of the usual NR130. This is because these versions of the NR application supply the option to playback an auditory equivalent of the entered SPL values and NR70 is considered a safe listening threshold. Table 1 shows relative dB SPL values for NRs across their octave bands, ranging from NR0 to NR70. This table's data was used to calculate NRs from user-input in the interactive applications.

B. User Input

Users first engage with MINR in the 'Plot' section where they enter dB SPL values for each octave-band listed. These data generate a black line-graph overlapping the preloaded multicolored line-graphs representing the standard NR curves (refer to the graph section in Fig. 2).

TABLE I. SOUND PRESSURE LEVELS PER OCTAVE BAND FOR EACH NR NUMBER FROM NR0 TO NR70 IN INCREMENTS OF NR5. ADAPTED FROM TEMPLETON AND SAUNDERS (1987, P. 29) PLOTTING NR0 TO NR130.

NR	Octave Bands (Hz)								
	31.5	63	125	250	500	1000	2000	4000	8000
	Octave Band Sound Pressure Levels								
0	55.4	35.5	22.0	12.0	4.8	0.0	-3.5	-6.1	-8.0
5	58.8	39.4	26.3	16.6	9.7	5.0	1.6	-1.0	-2.8
10	62.2	43.4	30.7	21.3	14.5	10.0	6.6	4.2	2.3
15	65.6	47.3	35.0	25.9	19.4	15.0	11.7	9.3	7.4
20	69.0	51.3	39.4	30.6	24.3	20.0	16.8	14.4	12.6
25	72.4	55.2	43.7	35.2	29.2	25.0	21.9	19.5	17.7
30	75.8	59.2	48.1	39.9	34.0	30.0	26.9	24.7	22.9
35	79.2	63.1	52.4	44.5	38.9	35.0	32.0	29.8	28.0
40	82.6	67.1	56.8	49.2	43.8	40.0	37.1	34.9	33.2
45	86.0	71.0	61.1	53.6	48.6	45.0	42.2	40.0	38.3
50	89.4	75.0	65.5	58.5	53.5	50.0	47.2	45.2	43.5
55	92.9	78.9	69.8	63.1	58.4	55.0	52.3	50.3	48.6
60	96.3	82.9	74.2	67.8	63.2	60.0	57.4	55.4	53.8
65	99.7	86.8	78.5	72.4	68.1	65.0	62.5	60.5	58.9
70	103.1	90.8	82.9	77.1	73.0	70.0	67.5	65.7	64.1

The application automatically calculates the difference between the entered SPL data and its closest corresponding NR curve above that entered value. These are displayed to the user in the 'Solve' section (Fig. 2). Based on these calculations, it is the entered SPL data point corresponding to the highest NR curve that results in the overall NR value, which is displayed to the user as a single value in the 'NR' box.

Using the values in Fig. 2 as an example, notice that the highest absolute dB value entered by the user is 90dB SPL (31.5 Hz band). This does not equate to placement on the NR90 curve, however, as this value needs to be aligned with its relative NR curve. As displayed in Fig. 2, this 90dB SPL value is -2.9 dB below its highest relative NR curve, which corresponds to the NR55 line in the case of 31.5 Hz octave-band. For the next octave band (63 Hz), the absolute dB value entered is lower (i.e. 80dB SPL) than that entered for 31.5Hz octave band. However, relative to the NR curves, this equates to a value that is -2.9 dB below the NR60 curve. Ultimately, the overall NR value in this example when taking all entered values into account is determined by the 76 dB SPL value entered for the 250 Hz octave-band. This absolute value is -1.1 dB below its highest relevant NR curve, which as seen from the black line-graph in Fig. 2 equates to the NR70 curve at the 250 Hz axis section.

C. Auditory Feedback

In addition to the visual-feedback offered in MINR, auditory-feedback options are also included. For initial volume calibration, a 'Pink Noise' button is provided. Users have the option to listen in isolation to the NR curve they generate based on the input-values they enter in the 'Plot' section using the 'NR Listen' button. This feedback would be the auditory equivalent of the black line-graph displayed in Fig. 2. The auditory output of NR Listen comprises a pink-noise source sent through a fast-fixed filter bank. This filter bank is composed of 10 bandpass filters where their center frequencies are set by the 9 NR octave-band frequencies, plus an 8500 Hz frequency that has a sharp gain drop. The bandpass filter gains of the 9 NR octave-bands are determined by the dB SPL values entered by the user in the 'Plot' section.

Additional audible feedback options are presented to the user to allow them to contextualize their generated NR curve. These comprise two playback buttons, one being an example of a softly played studio recording called 'Studio Sample' and another being a recording of heavy foundry machinery called 'Foundry Sample' (refer to Fig. 2). Users have the option to play these audio samples in isolation or with the generated audible NR output superimposed to represent background noise. Engaging the 'NR Listen' function concurrently with the recorded samples allows users to contextualize the impact (or lack of impact) of background noise in these different scenarios.

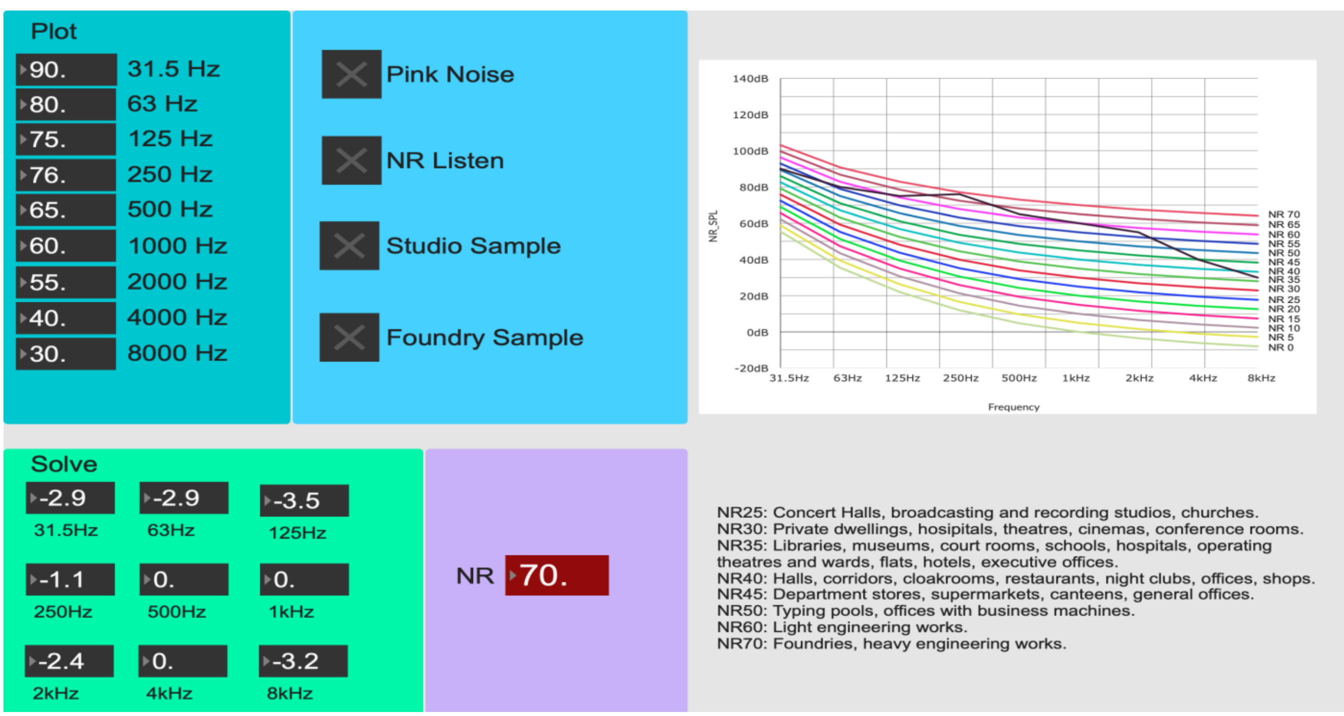

Fig. 2. The GUI of the Max version of MINR.

V. Application Evaluation

A. User-Study Basis

A user-study was designed to evaluate the effect of implementing MINR for teaching NR curves in a 1st-year undergraduate Acoustics module. The effect was measured by comparing the results from a test group (who used MINR) with that of a control group (who did not use MINR) in the cognitive domain. Data in the cognitive domain was gathered using a quiz that measured knowledge acquisition in the lower three levels of Bloom's taxonomy of learning (Bloom, B. 1956; Anderson. L. et al., 2001): information retrieval, understanding, and application.

Data was gathered in three stages: (1) pre-test, (2) post-test, and (3) three-weeks post-test. The pre-test was designed to establish the existing knowledge level of each cohort to be used as a reference to quantify learning gains. Additionally, pre-test data was also gathered to help identify differences between cohorts related to academic comfort level, motivation level, and average score in acoustics. The post-test knowledge quiz evaluates learning gains immediately after exposure to either experimental condition. The participant's scores three-weeks post-test were used to evaluate whether MINR had a significant effect on long-term learning.

B. Participants

Participants (N = 14) were 1st-year undergraduate music technology students over the age of 18 years old (M = 21.93; SD = 6.45). These participants were part of a two-semester long Acoustics class taught at the Technological University of the Shannon, Ireland. Students were split into two groups for the experiment (test group and control group). The MINR application was implemented during a 2-hour lab session for the test group while the control group received a non-multimodal task to complete during an equivalent lab session.

The demographic composition of both groups was similar but there were some key differences concerning the comfort level and motivation level of the cohorts. Interestingly, whilst the test group reported being more comfortable in Acoustics, they reported being less motivated to learn Acoustics (see Tab. 2). Both groups were informed that they were participating in a research project and provided their consent electronically. Data gathered was anonymized and ethical approval obtained prior to data collection.

C. User-Study Lab Setup

Both cohorts engaged with the NR curves task in a computer lab on campus comprising Apple Mac mini desktop computers from 2014 with 2.6 GHz Intel Core i5 processors and 8GB 1600MHz DDR3 memory running macOS High Sierra 10.13.6. All participants were provided with identical pairs of Sennheiser Model HD380 Pro headphones.

The listening level on all headphones was calibrated to 70dBC SPL using a pink noise source, represented as 23% on the Mac mini volume slider. To calibrate the headphones, a 5kg weight plate was placed on the headphone cushions to model the seal created when the circumaural headphones are placed on the head of a listener. A hole in the center of the weight plate allowed for the insertion of a Sound Level Meter microphone to obtain the output measurement that would be presented to a wearer's auditory canal. Participants were not permitted to adjust the playback level of the headphone during the test.

TABLE II. Demographic data for the test group and the control group with N = 7 students per group.

		Test Group	Control Group
Gender	Female	3	1
	Male	4	6
Preferred learning material	Exercises Activities	6	6
	Lectures Slides	1	1
Previously studied physics/acoustics		1	1
Academic comfort level in acoustics[a]		4.0 +/- 0.57	2.85 +/- 1.46
Motivation to learn acoustics[b]		3.28 +/- 0.95	4.28 +/- 0.76
Average score in acoustics[c]		67.14 +/- 8.93	64.28 +/- 14.23

[a]Data gathered on a 5-point Likert scale from very comfortable (5) to very uncomfortable (1). Mean score reported +/- standard deviation.
[b]Data gathered on a 5-point Likert scale from extremely motivated (5) to not at all motivated (1). Mean score reported +/- standard deviation.
[c]Average score reported as % of final grade in Acoustics module +/- standard deviation.

D. Materials

A ten-minute video lecture on the topic of NR curves was created and 14 knowledge domain multiple-choice questions were developed from the content presented in this lecture. Participants were provided with these quizzes 1 week before the test, immediately after completion of the test, and 3 weeks later to evaluate long-term learning. The multiple choices questions measured three learning taxonomy levels: information retrieval, understanding, and application (see Tab. 3). These questions were identical at each stage (pre, post, 3-weeks post) and randomized for every participant and each stage.

TABLE III. Number of questions aligned with Bloom's Taxonomy

Bloom's Taxonomy Level	# questions aligned with taxonomy level
Remembering	2
Understanding	6
Applying	6

E. Procedure

Once the online participant consent form was completed no further input was provided by the research coordinator. Participants in both cohorts watched the ten-minute video lecture on the topic of NR curves at the beginning of the test. The test group then engaged with MINR while the control group engaged in identical tasks using Microsoft Excel.

For the practical task, participants in each group were presented with a table of recommended NR curve values and the environments for which each NR value is appropriate. This had similar text as found in MINR's bottom-right GUI section (see Fig. 2). Participants were then provided with PowerPoint slides displaying examples of four environments; a concert hall, cinema, library, and foundry, along with a set of values for each 1:1 octave band from 31.5Hz – 8kHz for each environment.

The test group were asked to plot the values for each given environment using MINR, while the control group were asked to plot the values using a Microsoft Excel NR plotting spreadsheet by Building Calculators (2019). When the values for each environment had been plotted, participants were tasked with deciding if the overall NR value provided by either MINR or the spreadsheet was appropriate for the given environment by measuring their calculated values against the table of recommended NR values. Participants were given 30 minutes to engage with the practical task and were then asked to complete the 14 multiple choice questions.

VI. Study Results

A one-way between groups ANOVA was used to compare the average quiz score between each taxonomy level (Remember, Understand, Application) and each test stage (pre, post, 3-weeks post). This was followed by Tukey's multiple comparisons test.

For the Remember taxonomy level, the control group reported a significant difference in quiz scores at the $p < .05$ level for the three conditions [$F(2,18) = 7.875$, $p = .003$]. A post-hoc Tukey comparison test indicated that the mean score for the pre-condition ($M = 64.29$, $SD = 24.39$) was significantly different to the post ($M = 100$, $SD = 0$) and 3-weeks post ($M = 92.86$, $SD = 18.90$) conditions. However, the 3-weeks post condition did not significantly differ to the post condition. Similarly, there was a significant difference between the three conditions in the test group [$F(2,18) = 8.06$, $p = .003$] with a post-hoc Tukey comparison test also indicated that the mean score for the pre-condition ($M = 35.71$, $SD = 24.39$) was significantly different to the post ($M = 78.57$, $SD = 26.72$) and 3-weeks post ($M = 85.71$, $SD = 24.40$) conditions. Again, the 3-weeks post condition did not significantly differ to the post condition.

A one-way between groups ANOVA was conducted on test scores in the Understand taxonomy to compare the effect of the teaching method on participant quiz scores in the pre, post, and 3-weeks post-test conditions. The control group reported no significant difference in quiz scores at the $p < .05$ level for the three conditions [$F(2,18) = 0.250$, $p = .781$]. However, there was a significant difference between the three conditions in the test group [$F(2,18) = 8.054$, $p = .003$]. A post-hoc Tukey comparison test also indicated that the mean score for the pre-condition ($M = 30.95$, $SD = 20.25$) was significantly different to the post ($M = 73.81$, $SD = 21.20$).

A one-way between groups ANOVA was conducted on test scores in the Application taxonomy to compare the effect of the teaching method on participant quiz scores in the pre, post, and 3-weeks post-test conditions. The control group reported no significant difference is quiz scores at the $p < .05$ level for the three conditions [$F(2,18) = 0.444$, $p = .649$]. However, there was a significant difference between the three conditions in the test group [$F(2,18) = 4.053$, $p = .035$]. A post-hoc Tukey comparison test also indicated that the mean score for the pre-condition ($M = 52.38$, $SD = 29.55$) was significantly different to the post ($M = 83.33$, $SD = 13.61$).

VII. Discussion

An interactive multimodal application called MINR was developed to support student learning of NR curves in an Acoustics module. The application was designed to overcome learning difficulties related to the complexity and broad variability of noise profiles represented by the same NR value. These difficulties were addressed by accompanying the visual representation of plotted data points with audio feedback. This audio feedback allowed students to audition the result of user-generated noise curves both in isolation and in simulated real-world contexts.

A quiz was designed to test whether students using MINR to complete practical lab-tasks would perform better that those using Microsoft Excel (visual modality only) for the same tasks. The results demonstrate that undergraduate students completing practical lab-work using the interactive multimodal approach recorded a significant improvement in their performance on questions relating to the Understand and Application levels of Bloom's taxonomy, over those students using MS Excel to complete the same task. This finding suggests that MINR improved the students' ability to understand and apply the information learned in the video lecture.

The improvement in student performance in questions addressing the 'Understand' taxonomy level was not surprising as computer simulations used in conjunction with traditional teaching methods have been found to improve students' conceptual understanding in science-based disciplines (Jimoyiannis and Komis (2001); Stern et al. (2008); Gelbart et al. (2009)). However, since both the control and test groups generated a visual representation of the data, this suggests that the primary benefits were derived from the inclusion of audio feedback to the learners. Therefore, it may be the case that audio feedback in MINR supports the development of more robust mental representations of NR curves than the visual modality alone. Learners using MINR were able to explore hypothetical situations, develop questions, and receive prompt visual and auditory feedback on their hypothesis (Van Berkum and de Jong 1991). This process of discovery and confirmation is known to help learners refine their conceptual understanding of complex phenomena (Windschitl and Andre 1998) and is an important component in inquiry-based learning approaches. Whilst both cohorts received visual feedback on their input data, the results suggest that the provision of audio feedback in the test group led to significant improvements in conceptual understanding and application.

It is worth noting that the method of audio feedback in MINR is more akin to auralization (Vorländer, 2020) rather than to sonification (Hermann et al. 2011), where situational information is provided to learners through acoustic simulation rather than providing them with an auditory equivalent for visualized data. In MINR, the auralization is a relatively simple, non-spatial presentation but with advances in immersive audio for VR, there is much discussion around the potential of auralization in education contexts (Pulella, 2021) (Chabot & Braasch, 2022). However, more empirical data is needed to assess the benefits and pitfalls of auralization across pedagogical parameters and learner experiences.

Although this study examined learning in the cognitive domain, prior research has demonstrated that computer simulations can have a strong impact on learning in the affective domain. These effects include an improved attitude towards the subject (Kilboss et al 2004) and increased interest (Baltzis and Koukias 2009). Affective outcomes were not measured directly in this study but we did observe that students in the test group asked more questions about the application design, appreciated the usefulness and importance of the task for measuring environmental noise, and demonstrated reflective thinking regarding the connection between the data and the visual representation. Conversely, the control group reported being intimidated by the Excel sheet and found the task to be tedious and confusing.

Interestingly, the findings suggest that participants in the control group did better than the test group in the 'Remember' taxonomy questions. To reiterate, the control group performed significantly poorer than the test group in 'Understand' and 'Application' questions, even after undertaking training. This supports the notion that it is important to choose the most appropriate teaching method to achieve the learning objectives (taxonomy level) required, and that in some cases, non-interactive (or static) presentation of topics is better from the learning perspective of the student. Therefore, taking into account the data in this study, for 1st-year acoustics students, a method that incorporates a mixture of teaching approaches (static and interactive) may more comprehensively accomplish the learning objectives across all taxonomies for topics such as NR curves.

Acknowledgment

This research was funded by the National Forum for the Enhancement of Teaching and Learning in Higher Education, under the SATLE programme. The authors express gratitude to the Department of Quality, Teaching and Learning at the Technological University of the Shannon for their support of this research.

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