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Instructional design effectiveness in emergency remote teaching of radiation protection and dosimetry

Efectividad del diseño instruccional en la enseñanza remota de emergencia de la protección radiológica y dosimetría

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RESUMEN: Esta investigación presenta el diseño instruccional (DI) aplicado para cambiar la asignatura de Protección Radiológica y Dosimetría de la modalidad presencial a la modalidad remota de emergencia, llevado a cabo en la Universidad de Tarapacá (Chile), y compara su efectividad en cada modalidad. El DI consideró los modelos de Dick *et al.* y Anderson, complementados con principios del enfoque de Harasim. La instrucción implementada incluyó sesiones sincrónicas estructuradas con los eventos de Gagné y actividades asincrónicas. Método: La efectividad del DI fue evaluada con el modelo de Kirkpatrick en el nivel 1 y 2. El primero se valoró a través de un cuestionario confiable de tres dominios calificado en una escala de 7 puntos y nueve preguntas adicionales basadas en la literatura mediante una escala Likert de 5 puntos; el segundo nivel comprendió las calificaciones obtenidas por los estudiantes en ambas modalidades. Resultados: 64 estudiantes completaron la encuesta en la modalidad presencial y 44 en la versión remota de emergencia. Los estudiantes percibieron que el instructor hizo que el contenido fuera más interesante en la versión remota ($p=0.015$), además percibieron que las evaluaciones en línea permitieron una evaluación más justa de sus habilidades ($p=0.002$) y que el sistema de evaluación fue más apropiado para el curso ($p=0.007$). Destaca la mayor percepción del desarrollo de habilidades escritas ($p<0.001$) y la capacidad de planificar su propio trabajo ($p=0.001$). El 86% de los estudiantes consideraron que la metodología remota tiene iguales o mayores ventajas que la metodología presencial. Se observaron calificaciones similares en ambas modalidades de entrega ($p=0.099$). Conclusión: A pesar del cambio repentino de modalidad, la versión remota de emergencia de la asignatura diseñada mostró niveles más altos de satisfacción y tasa de aprobación del curso que la modalidad presencial.

PALABRAS CLAVES: Diseño instruccional; enseñanza remota de emergencia; satisfacción estudiantil; enseñanza de la Física Médica.

INTRODUCCIÓN

Medical uses of ionizing radiation represent the main source of artificial exposure to the world's population (UNSCEAR, 2019). The judicious use of ionizing radiation is a challenge because their health effects are stochastic in nature, as evidenced by the increased probability of carcinogenic induction as the absorbed dose increases (ICRP, 2007). The rational use of ionizing radiation allows maximizing the benefit derived from the procedures that use it; medical physics and part of its subdisciplines, radiation protection and dosimetry, oversee this task (Ubeda *et al.*, 2020).

Radiation protection is a field dedicated to implementing strategies to reduce unnecessary exposure to ionizing radiation (Frane & Bitterman, 2021), while dosimetry is a science that determines the dose and dose distribution absorbed by a subject (patient, worker, or public) from a radiation source (Amols, 2002). Therefore, training in these subdisciplines is a fundamental aspect to protect the health of those who are irradiated.

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Training in medical physics has been mostly face-to-face, so the consequences associated with the strategies aimed at containing the coronavirus pandemic (COVID-19) –such as social distancing and partial closure of much of the nonessential services, including higher education– prompted universities to innovate in their teaching methods (Núñez-Cortés, 2020; Haworth *et al.*, 2020; Penprase, 2018). The innovation of teaching in pandemics involves the shift in the teaching modality from face-to-face to virtual as well as the incorporation of technologies and media in formative processes (Adedoyin & Soykan, 2020) to give continuity to the curriculum in all areas of knowledge, including medical education (Lucaey & Johnston, 2020) and medical physics training (Paz *et al.*, 2019).

It is important to state that the change of modality in a subject in the context of pandemic, although it implies distance learning, is conceived as an emergency remote teaching. Hodges *et al.* define it as a temporary and alternative change in the mode of delivery of education due to the circumstances, involving the use of fully remote learning solutions that in normal contexts are delivered face-to-face, that will return to their original format once the emergency or crisis circumstances that cause them have ended; and is different from traditional online learning (e-learning), which is built with sufficient time and on the basis of specific didactic principles, rather than a forced adaptation from face-to-face to virtual, as in this case (Hodges *et al.*, 2020).

Evidence shows that properly implemented virtual teaching enriches the educational experience compared to face-to-face teaching (Azar *et al.*, 2021). To achieve more effective instruction and motivate students in their learning process, it is essential to implement an appropriate instructional design (ID) model. ID improves student learning, which requires teachers to plan, implement and evaluate their instruction (Rapanta *et al.*, 2020). The ID in virtual methods considers strategies to guide students in their training and provide them with flexibility for continuous learning at their own pace, according to their context at home (Mospan & Slipchuk, 2020; Azlan *et al.*, 2020; Alsoufi *et al.*, 2020; Harries *et al.*, 2021).

1.1. Study context

The Medical Technology Program, with specialization in Imaging and Medical Physics at the Universidad de Tarapacá, has conducted radiation protection and dosimetry mostly in person and has considered this course a hallmark in the training of its students since 1982. The pandemic demanded a complete shift from face-to-face to virtual activities.

The ID of the subject evaluated in the present study first considered the model of Dick *et al.* (Dick *et al.*, 2014), an ID methodology that conceives of the formative process as iterative, based on the ADDIE concept, acronym for Analyze, Design, Develop, Implement, and Evaluate. This approach has been successfully applied to medical curricula and represents a useful strategy to develop IDs (Jabaay *et al.*, 2020), allowing us to solve difficulties in the acquisition of skills and knowledge through the development of learning solutions under a structured process (Branch, 2009; Bates, 2019).

The framework for instruction was complemented with Anderson's model, which establishes the dynamics of the relationships between students, instructors, knowledge, learning activities, and the communication on which the subject was developed (Anderson, 2008). To enhance virtual learning, constructivist teaching based on a collaborative learning model, proposed by Harasim, was considered. Harasim's approach is especially useful in pedagogic group discussion and considers a three-phase process: idea generation, focused on divergent thinking within a group; idea organizing, which comprises a conceptual change that arises from the meeting of one's own ideas and those proposed by others; and intellectual convergence, where collective learning through collaboration arises (Harasim, 2017).

After the ID process, the implementation of online instruction required considering the student's processing of information, which was achieved by applying the principles of Gagne's 9-events of instruction: gain attention, inform learner of objectives, stimulate recall of prior learning, present information, or stimulus, provide learning guidance, elicit performance, provide feedback, assess performance, and enhance retention and transfer (Miner *et al.*, 2015).

Finally, Kirkpatrick's model provided elements to assess the effectiveness of the ID implemented and provided feedback for the continuous improvement of the ID in future versions of the subject (Smidt *et al.*, 2009). The relationship between theories, models and approaches considered in the presented ID are schematized in Figure 1.

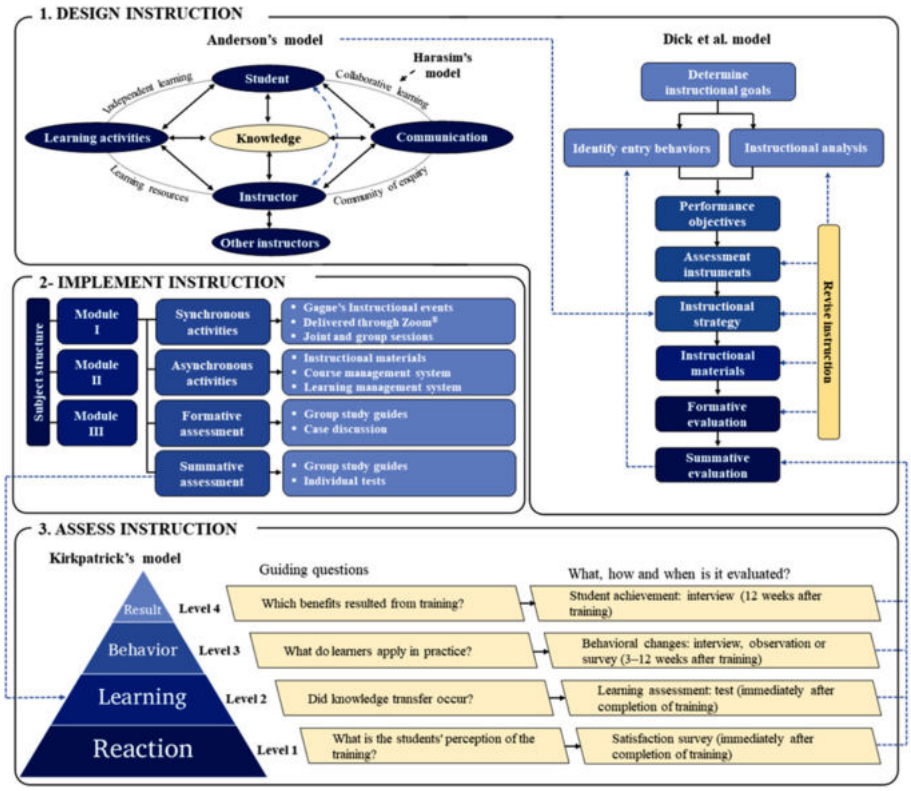

Figure 1. Instructional design framework for emergency remote teaching of radiation protection and dosimetry subjects. First, the process of instructional design considered the model of Dick *et al.* (2014) and elements from Anderson's model (Anderson, 2008), complemented with the principles of collaborative learning proposed by Harasim (2017). Second, the implementation of instruction considered synchronous sessions structured by applying Gagne's 9 events (Miner *et al.*, 2015), asynchronous activities, and formative and summative assessments. Finally, Kirkpatrick's model was applied to evaluate the efficiency of learning achieved through the proposed model (Smidt *et al.*, 2009), whose information allows the model to be fed back into the continuous improvement of the course; the present report considered only the first two levels (reaction and learning).

There is published evidence of successful outcomes with varied ID in multiple fields of training (Azar *et al.*, 2021; Azlan *et al.*, 2020). Available reports demonstrate favorable results through these approaches; however, the approaches are centered mainly in medical education (Alsoufi *et al.*, 2020; Tuma *et al.*, 2021) and postgraduate programs in medical physics (Azlan *et al.*, 2020), with little development regarding the ID applied in the transition to emergency remote teaching in undergraduate medical physics programs, as well as assessing the effectiveness of the training developed from this perspective.

1.2. Design and delivery of emergency virtual learning

The ID in the emergency remote version of the subject was consistent with the formative purpose of the face-to-face version through the course syllabus but added elements that enriched learning in a virtual environment. Along with the ID aspects mentioned in the previous section, the use of a learning management system (Moodle 3.9) was considered, which allowed the dissemination of the educational resources of the subject.

The formats for subject delivery were defined according to institutional requirements, which considered the use of the Intranet platform (Course Management System), Moodle platform, Zoom application (Zoom Video Communications, San Jose, CA, United States) and online video-sharing platform (YouTube, San Bruno, CA, United States). The university prevented technological difficulties for students (connectivity and computer equipment availability) by

providing tablets and mobile broadband devices to those who needed them. To reduce learner-related problems due to the use of new delivery channels and to favor the technical expertise of the students, a one-month training period was conducted.

To replace the practical activities, synchronous sessions were conducted through the Zoom platform in two modalities. The first was performed to analyze theoretical contents, experimental setups, and calculation formulas with all the students of the course. The second considered online group sessions (five students each), which allowed us to apply the knowledge, receive personalized feedback, and develop the social dimension of the students. To increase the meaningfulness of learning, stimulate critical thinking and develop interpersonal skills, students participated in guided discussions and frequently presented their queries and contributions (FAO, 2021) through Zoom chat and spoken interventions (synchronous) or via e-mail, Moodle forum, and the Intranet (asynchronous). All sessions were recorded at 1080p resolution and then uploaded to YouTube (YouTube Inc., San Bruno, CA, United States) to be available to students until the end of the semester.

Active-participative classes were conducted as an expository method to facilitate learning, guide, and motivate students (FAO, 2021). Factual knowledge, case analysis and solved exercises were reviewed using PowerPoint (Microsoft Corp., Redmond, WA, United States) presentations. These presentations included didactic diagrams of the setups performed in the radiographic room as those used in the face-to-face version of the course. Table I summarizes the main aspects of the instructional process for the face-to-face and emergency remote version of the subject.

1.3. Purpose of study

The aim of this work is to present the ID applied in the shifting from face-to-face to emergency remote delivery of radiation protection and dosimetry and to compare its effectiveness in each context, unraveling the following research questions (RQs):

RQ1: What differences are there in the satisfaction of students who took the face-to-face versus emergency remote modalities of radiation protection and dosimetry?

RQ2: What effects does the change in delivery modality and the ID applied have on student performance?

The results obtained will serve as a basis for further research in this field, applying or modifying the proposed ID framework and favoring the training of students in medical physics.

Table I. Comparison of instructional design between the face-to-face and emergency remote version of the Radiation Protection and Dosimetry subject.

Aspect	Face-to-face version	Emergency remote version
Learning activities	Hands-on laboratory activities. Handbook for practical activities. Face-to-face discussion of contents. Laboratory report activities.	Synchronous joint and group sessions (Zoom). Viewing of videos from sessions and related videos (YouTube). Group guides. Online discussion of contents. Online discussion of group guides.
Assessment	Partial N° 1 (individual: 1.5 h). Partial N° 2 (individual: 1.5 h). Final (individual: 1.5 h). Closed book (all).	Partial (individual: 8.0 h). Process (group guides: one week). Final (individual: 8.0 h). Open book (all).
Communication	Verbal (face-to-face), email, Intranet.	Verbal (online), Zoom chat, email, Intranet, Moodle forums.
Student engagement	Face-to-face interactions.	Virtual interactions.
Information storage	Intranet website.	Intranet. Moodle platform.
Attendance record	Signature on the attendance sheet.	Zoom use report.

MATERIALS AND METHODS

2.1. Study design and participants

This research was conducted using a cross-sectional design. The participants were students who took the Radiation Protection and Dosimetry subject at the Universidad de Tarapacá (Arica, Chile) in face-to-face (2019) or emergency remote (2020) delivery formats. The sample size was estimated considering a population of 117 students, with a confidence level of 95% and a 5% error, requiring a minimum sample of 90 subjects.

2.2. Assessment of learning effectiveness

The effectiveness of training was assessed according to levels 1 and 2 of Kirkpatrick's evaluation model (Smidt *et al.*, 2009). According to Kirkpatrick's evaluation level 1, a two-section self-administered instrument was designed to determine the satisfaction of the students with the ID. The instrument was applied in Spanish and is presented translated in the article to maintain language consistency with the manuscript.

The first section corresponded to a scale previously validated (Table II) and constructed based on the instrument published by Fieger in 2012 (Fieger, 2012) and a literature search (Strong, 2012). The scale consisted of twelve items distributed in three domains: teaching, assessment, and generic skills. Each question was rated on a 7-point scale (extremely poor to exceptional) according to the level of agreement with each statement. The instrument was applied at the end of the semester in paper format to sixty-four students who took the course in face-to-face version and, via Google Forms (Google LLC, Mountain View, CA, United States), to forty-four students who took the emergency remote version of the subject.

The second section of the instrument consisted of a questionnaire designed to analyze the student's satisfaction in specific aspects of the ID in the pandemic context and was applied only in the emergency remote version of the subject (Figure 3). This section provided a more in-depth analysis of online teaching through nine questions extracted from the literature (Strong, 2012), rated on a 5-point Likert scale (strongly disagree to strongly agree).

Kirkpatrick's level 2 was evaluated through the average of the final grade obtained by the students who participated in each version of the course. The details of the evaluation system applied are shown in Table 1 and considered a grading scale from 1.0 to 7.0, with a 70% requirement to obtain the minimum passing grade (4.0).

2.3. Data processing

The data were tabulated and statistically analyzed using the statistical package SPSS (IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp). The normality test was used, followed by the Levene homogeneity of variance test. The scores obtained on the satisfaction scale are presented as the median (interquartile range (IQR)). Data from the student satisfaction questionnaire are presented as percentage frequencies. The final grade obtained by the students in both versions is presented as the mean (standard deviation (SD)). The comparison of differences in the medians or means of the variables for both cohorts of students was performed using the Mann-Whitney U test or Student's t-test, according to the normality of the variables. Values of $p < 0.05$ were considered significant.

2.4. Ethical considerations

The recruitment of the participants was authorized by the Head of Medical Technology with specialization in the Imaging and Medical Physics Program. In addition, the recommendations of the Declaration of Helsinki were followed. All participants gave informed consent before answering the survey. The data obtained were anonymized and stored securely; only the research team had access to them for the development of the study.

RESULTS

3.1. Sample characteristics

Of 117 students who took radiation protection and dosimetry in 2019 and 2020, 108 responses were received (92.3% response rate). Of these, 59.3% (n = 64) corresponded to students who took the class in face-to-face mode and 40.7% (n = 44) in emergency remote delivery mode.

3.3.1. Kirkpatrick's model level 1: Student's reaction

The comparative results of student satisfaction obtained in the face-to-face and emergency re-

mote versions of the subject, according to the first part of the questionnaire applied, are presented in Figure 2. In six of the twelve questions, significant differences were observed between the two methodologies evaluated. The emergency remote version presented higher median scores than the version obtained in the face-to-face modality.

Teaching was the best evaluated domain in the survey (median = 7.00, IQR = 0.25), according to the students' satisfaction scores (Figure 2); students considered that the instructor made the topics more interesting in the emergency remote version ($p = 0.015$) than in the face-to-face mode. The second-best rated domain was the Assessment (median = 6.25, IQR = 0.75); in the emergency remote version of the subject, students perceived a higher level of satisfaction considering the evaluations as a fairer test of their skills ($p = 0.002$), in addition, they highly accepted the system of evaluation ($p = 0.017$) and the open-book assessments applied ($p = 0.007$). Finally, for the generic skills domain (median = 6.00, IQR = 0.94), students perceived a significant improvement in their written communication skills ($p < 0.001$) and in the development of their ability to plain their work ($p = 0.001$).

The level of agreement for the questions applied only in the emergency remote version of the subject is summarized in Figure 3. There is high acceptance with the ID used in the course, especially with the order of the contents that favored their learning (with an agreement of 20.5% and a strong agreement of 79.5%), and with the pace of work that was considered appropriate by 43.2% of the students and very appropriate by 56.8% of them. Other aspects with a predominance of acceptance (97.7% agreement or strong agreement) were the development of the group work guides with feedback from the instructor, the realization of the joint sessions and the high didactic quality of the presentations.

The contribution of the Moodle platform to the development of the subject was considered high or extremely high by 75.0% of the students. Regarding the advantages and disadvantages of the emergency remote methodology, 64.0% of the students consider that it brings more advantages than face-

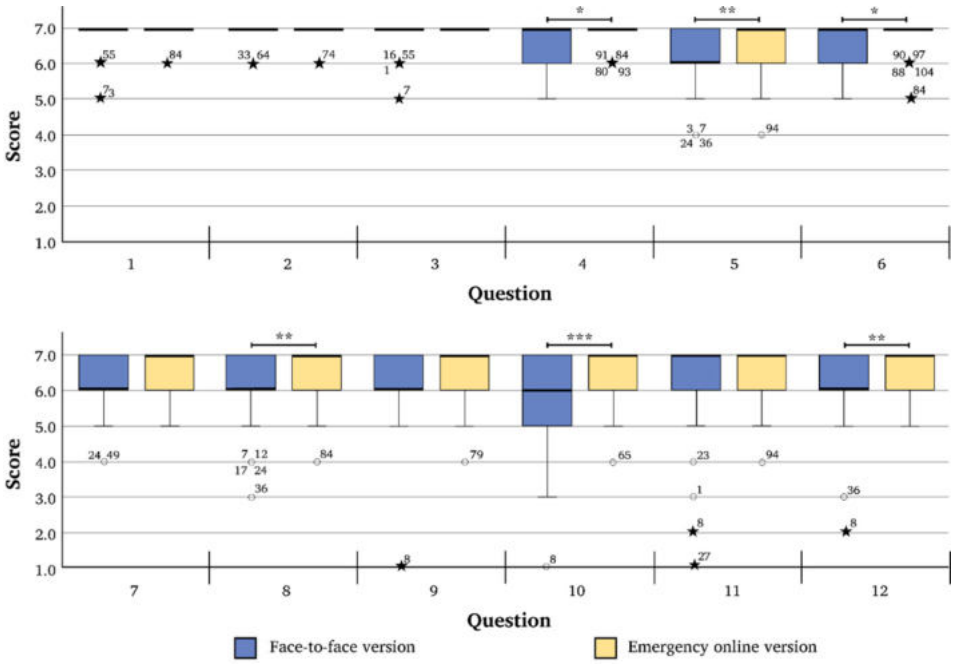

Figure 2. Student satisfaction in face-to-face and emergency remote versions of the Radiation Protection and Dosimetry subject. Questions 1 to 4 correspond to the teaching domain; 5 to 8 belong to the assessment domain and 9 to 12 to the generic skills domain. Boxes represent the interquartile range, the line in between the median value. The vertical bars extending to the highest and lowest values (excluding outliers), outliers (○) and extreme values (★) are presented. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$ for Mann-Whitney U test.

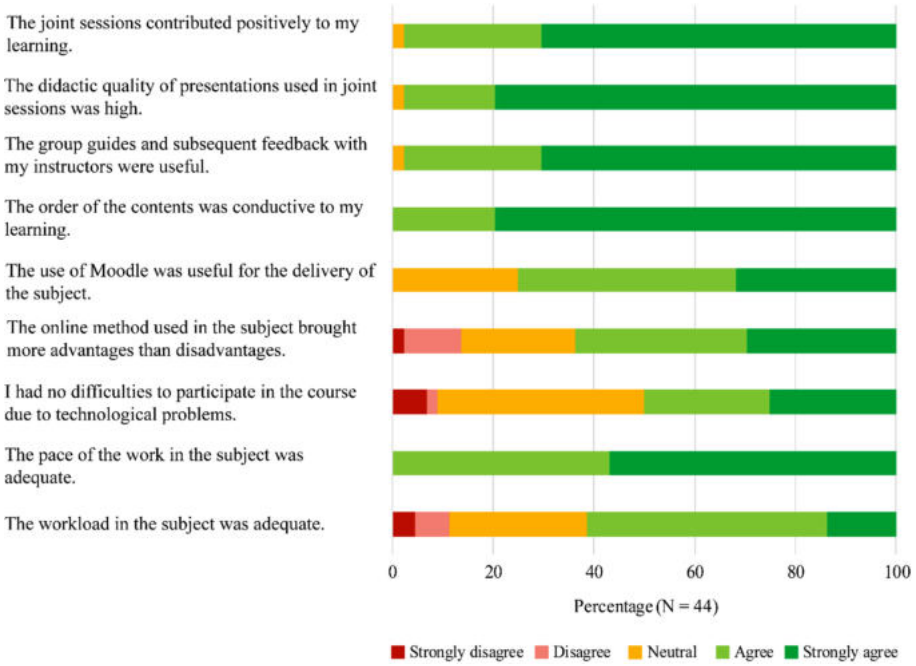

Figure 3. Student satisfaction with the applied instructional design in the emergency remote version of the Radiation Protection and Dosimetry course (2020). Data are presented as percentage frequencies of the levels of agreement to each statement.

to-face teaching, while 22.0% consider that there is a balance between them. The aspects with lower acceptance were associated with difficulties due to the online methodology and participation in online activities, as well as the workload.

3.3.2. Kirkpatrick's model level 2: Learning assessment

Figure 4 shows the distribution of the grades obtained by students who took the radiation protection and dosimetry subject both face-to-face (2019) and emergency remote versions (2020). In face-to-face mode, students registered a mean grade of 4.87 (0.86), while in emergency remote mode, the mean was 5.12 (0.68). There were no significant differences between the two cohorts of students (p = 0.099). The pass rate for the subject increased from 90.1% in the face-to-face version to 97.8% in the emergency remote version.

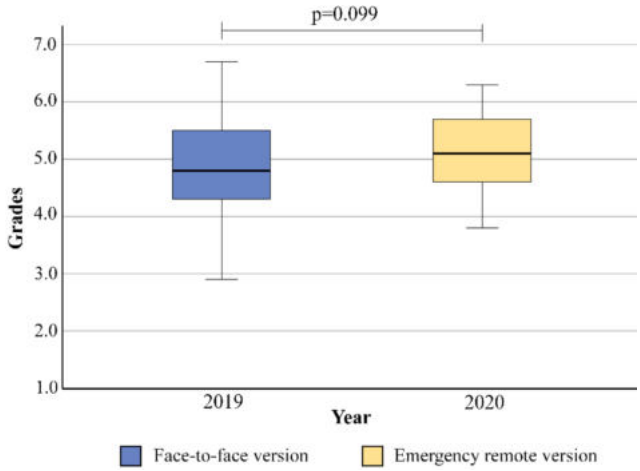

Figure 4. Grades obtained by students who took the Radiation Protection and Dosimetry course face-to-face (N = 64) and in emergency remote versions (N = 44). Data are presented as percentage frequencies of the level of agreement to each statement. Boxes represent the interquartile range, the line in between the median value. The vertical bars extend to the highest and lowest values. P values indicate the level of significance for Student's t-test.

DISCUSSION

COVID-19 imposed dramatic changes on the educational system (Azlan *et al.*, 2020; Lapitan *et al.*, 2021). Instead of conceiving of the current context as a disruption, we should conceive of it as a catalyst for the transformation of medical education that was decades in the making (Lucey & Johnston, 2020).

However, ensuring continuity and access to education in a pandemic context has required the shift from face-to-face to emergency remote teaching (Hodges *et al.*, 2020), which implies providing a learning experience enriched with technological means and resources (Rapanta *et al.*, 2020; Azlan *et al.*, 2020).

To facilitate learning, a high-quality ID is required because it is associated with devising clear learning objectives, structuring content carefully, integrating relevant media and activities for students, considering assessments strongly linked to learning outcomes, and controlling the cognitive load of students (Yang, 2017; Güney, 2019). These considerations are relevant in every instance of the training process and even more so when the context drags us toward a transformation of our practices; one way to address them is with an ID based on models and principles that are applicable to our situation.

A systematic review of the ID models published in 2020 highlights among them the four-component ID (4C/ID), Instructional Project Development and Management, Morrison *et al.*, ASSURE (Analyze, State objectives, Select materials, Use materials, Require learner response and Evaluation), ADDIE, and the proposed by Dick *et al.* (Stefaniak & Xu, 2020). The present study considered Dick *et al.*'s model as a cornerstone to give a sense of process and continuous improvement of course development, allowing students to enhance the learning experience in future deliveries of the course until they reach the goals in the best way (Dick *et al.*, 2014). Published reports support its application in the configuration of medical education and its effectiveness, underscoring their ease of application, even for novice instructional designers, making them suitable strategies for ID in higher education (Azar *et al.*, 2021; Jabaay *et al.*, 2020; Alnajdi, 2018).

Despite the advantages associated with ID models, there are criticisms that suggest they provide a limited view of the educational environment (Stefaniak & Xu, 2020). This limited view was prevented in this study by complementing the ID model with other approaches (Figure 1), such as Anderson's model (Anderson, 2008) strengthened with elements from Harasim's model (Harasim, 2017), fostering collaborative learning and improving instructors' guidance in selecting resources for learning.

A report published by Azar *et al.* demonstrated the success of an integrated ID model in the context of the pandemic based on blended learning delivery, which was applied in the Fundamentals of Epidemiology and Biostatistics subjects (Azar *et al.*, 2021). This evidence is useful from the point of view of scientific disciplines linked to the medical field and can be associated with reports such as those of Azlan *et al.* (2020), which focus on student satisfaction with respect to the means and methods used in virtual training of the Master of Medical Physics Programme. However, there is a scarce development of publications addressing the training and education of students from a formal ID perspective in medical physics; consequently, this study can be a step forward in this sense.

The delivery of instruction is a relevant stage in the virtual training process, where communication between key actors is fundamental to achieve student engagement (Yang, 2017), requiring considering varied instances of interaction: asynchronous and synchronous. Asynchronous activities allocate students to self-regulate their training and pace of work. Synchronous activities favor collaborative work and allow the generation of a more personalized learning experience, essentially when they are structured based on learning theories, such as those proposed by Gagne (Miner *et al.*, 2015), which have shown successful results in medical education, as reported by Woo (2016).

A simple, practical, and widely used model for structured evaluation of a training program is Kirkpatrick's model (Alsalamah & Callinan, 2021). This approach considers four levels that allow monitoring that the training meets the needs and requirements of the organization that delivers the program as well as those who participate in it (Smidt *et al.*, 2009). In our case, we use Kirkpatrick's model in an undergraduate university training context, similar to other works that have made this adaptation with successful results (Alsalamah & Callinan, 2021). Only the first two levels of Kirkpatrick's model were evaluated due to health contingency and feasibility difficulties.

The first level of the model corresponds to the reaction level. Reaction is a construct that can be addressed through the general satisfaction evaluation or through the evaluation of multiple criteria such as training materials, methods, and instructional activities (Alsalamah & Callinan, 2021).

In the teaching domain, the students considered interesting the way in which the instructor taught

the subject topics (Figure 2) and perceived the didactic quality of the class material as high quality (Figure 3), which constitutes a factor that from teaching favors the students' engagement and performance (Basuony *et al.*, 2020) and that is supported by the good academic performance observed in the emergency remote version (Figure 4).

For the second domain, evaluation, students positively scored the evaluation system implemented during the semester (Figure 2). This situation is consistent with the report of Tarik & Hassan (2018), who found a positive relationship between the use of continuous evaluation systems and student motivation for a group of students in the medical area.

Some authors have reported that low levels of anxiety in students favor formative processes (Akcil & Bastas, 2021); therefore, in the proposed ID, the evaluation was conceived as part of the formative process, considering individual and group open-book evaluative instances. Although there are apprehensions in their use, it has been reported that they allow the recognition of students' skills in a way similar to closed-book assessments, for which it is essential to elaborate an appropriate set of questions; these assessments adequately represent real-life situations in which problems are posed and multiple resources are available to develop appropriate solutions (Brightwell *et al.*, 2004); therefore, they are valid tools as part of the training process of this discipline.

From the point of view of the third domain evaluated (generic skills), Azlan *et al.* (2020) recognize the relevance of student independence and self-regulation in the context of emergency remote teaching, so ID should consider activities that favor this dimension. The students who participated in the present study demonstrated a high capacity to adapt to circumstances, which is associated with the development of their ability to self-regulate their learning (Tabakova, 2020).

Within the additional questions presented in Figure 3, one of the elements that support the implementation of emergency remote teaching is the use of platforms that facilitate the dissemination of the subject, such as the Moodle platform implemented by our institution. The positive evaluation of the students in the use of the platform is consistent with Tabakova's report, which recognizes the contribution of these media in the training in medical physics (Tabakova, 2020).

The migration to new virtual platforms to support emergency remote teaching has been associated with the work overload reported by students and teachers (Adedoyin & Soykan, 2020). Our results show that 66% of the students perceived the workload of the course as high or very high, possibly because the subject evaluated was taught in the first semester of confinement and transition to emergency remote mode, which is an important stress factor for these stakeholders (Ihm *et al.*, 2021).

The article by Almusharraf and Khahro (2020) identified multiple critical aspects that could affect learning in virtual environments, including the lack of professional technological training and technical issues. In our case, connection difficulties were minimal (Figure 3) thanks to the provision of tablets and mobile broadband devices to those who required them, as well as the allocation of a period of training and white march before the formal start of classes, elements that should be considered by the institutions in the event of similar scenarios in the future.

Our experience was better than the experience reported by other authors (Azlan *et al.*, 2020; Tuma *et al.*, 2021); nevertheless, it should be considered that the feasibility of implementing emergency remote teaching depends on multiple contextual factors, such as the resources available in the institutions and the socioeconomic level of the students.

Finally, the second level of Kirkpatrick's model, related to the acquisition of learning in the cognitive, procedural (skills-based) and attitudinal domains, is denoted by an increase in the level of knowledge, the improvement or development of skills, and the development of favorable attitudes on the part of the participants (Alsalamah & Callinan, 2021). This level was approached from the point of view of the final grade obtained in the course.

According to Figure 4, students' performance was not affected by the emergency incorporation of online methods in the pandemic context. This observation is congruent with what has been reported in similar ID approaches (Azar *et al.*, 2021), demonstrating that, for certain learning achievements, emergency remote teaching allows reaching a level of competence similar to that provided by face-to-face training, providing evidence that could contribute to resolving a concern in medical physics about the need to resume face-to-face activities in the training of professionals once the pandemic is over or sanitary conditions are favorable (Haworth *et al.*,

2020) and to consider the enrichment of training through mixed delivery methods (blended learning).

4.3. Limitations and considerations

This is the first report in Chile on ID in the adaptation from face-to-face to emergency remote mode and where satisfaction of undergraduate students in medical physics in both contexts was measured. Some limitations of the present study are that satisfaction was assessed in a public and regional university in Chile, which places the results in a particular geographical and socioeconomic context. The results obtained are valuable inputs for decision-making at the local level; therefore, larger-scale studies are required for appropriate generalization.

Our findings underscore the importance of decreasing student workload and improving institutional policies to eliminate technology access gaps among students. They also provide information on undergraduate student satisfaction under the applied ID, which is a baseline for exploring the dynamics of student training in radiation protection and dosimetry as partial closure continues.

As other reports have pointed out (Adedoyin & Soykan, 2020; Tuma *et al.*, 2021), it is essential to consider that the transition to emergency remote teaching in the pandemic context is not standard virtual training, essentially because of the urgency of methodological change. The continuous qualification of teachers in ID is essential to better guide the training of students. Future research can address the topic from the perspective of monitoring the evolution of teaching-learning processes and educational innovation practices generated by the contingency.

CONCLUSIONS

Emergency remote teaching due to the pandemic accelerated the incorporation of methodological strategies to enrich the educational experience of students in all disciplines, including medical physics. An ID based on learning models and theories and properly implemented is key to meeting the learning needs of our students from formal, intentional, and systematic perspectives.

Despite the sudden change of modality and the scarce previous experience for learning in virtual environments, the emergency remote mode showed higher levels of satisfaction than the face-to-face mode. Even though the ID implementation partially modified the final grades of the students, it produced a lower dispersion in the academic results and reduced the failure rate of the subject. Based on the results, the implementation of technological means in future versions of the Radiation Protection and Dosimetry subject is a complement to enhance traditional classroom training, both during and at the end of the pandemic.

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ABSTRACT: Purpose: This research presents the instructional design (ID) applied to shift the Radiation Protection and Dosimetry subject from face-to-face to emergency remote mode, conducted at the Universidad de Tarapacá (Chile), and compares its effectiveness in each delivery format. ID considered the models of Dick *et al.* and Anderson, complemented with principles from Harasim's approach. Implemented instruction involved synchronous sessions structured with Gagne's events and asynchronous activities. **Method:** The effectiveness of ID was as-sessed with Kirkpatrick's model level 1 through a reliable three-domain questionnaire scored on a 7-point scale and nine additional questions from the literature on a 5-point Likert scale; level 2 comprised grades of students obtained in both delivery modalities. **Results:** A total of 64 students completed the survey face-to-face, and 44 students completed the emergency remote version. Students perceived that the instructor made the content more interesting in the remote version ($p = 0.015$). Students felt that the online assessments allowed for a fairer evaluation of their skills ($p = 0.002$) and that the evaluation system was more appropriate ($p = 0.007$). A perception of the development of written skills ($p < 0.001$) and the ability to plan their own work ($p = 0.001$) stands out. Eighty-six percent of the students considered that the remote methodology has equal or greater advantages than the face-to-face methodology. Similar grades were observed in both delivery modalities ($p = 0.099$). **Conclusion:** Despite the sudden change of modality, the emergency remote version of the subject designed showed higher levels of satisfaction and pass rate of the course than the face-to-face mode.

KEYWORDS: Instructional design; emergency remote teaching; student satisfaction; medical physics training.

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