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Can we do real inquiry online? Influence of real-time data collection on students' views of inquiry in an online, multi-site masters' degree on environmental education

Francisco-José Castillo-Hernández[1] · María-Rut Jiménez-Liso[1] · Digna Couso[2]

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Abstract

In a previous study we detected that a number of inquiry stages (data collection, analysis and conclusions) went unnoticed by the students of an in situ joint online/onsite master's degree via online teaching. In this paper we analyse the effect of improved instruction, in which students fully experienced and became aware of all the stages that comprise the inquiry-based teaching approach. In the article we show the differences between the initial and improved instruction. The comparison of student comments as exhibited in the online *class diary* forum between the initial and improved instruction has allowed us to analyse the influence of this improvement in the level of depth of the students' discourse. Two codings have been employed to analyse the forums: the first (deductive) detected which stages of inquiry appeared in the comments. The second (inductive) involved the recoding of each of the previously classified comments based on five levels of communicative quality that emerged. Our main finding was that as well as being more aware of the different stages of inquiry, the students of the improved investigation were able to explain and identify them with specific examples. In other words, the investment of time in developing each of the stages in question helped them to define, afford reality to, and increase the explicative quality of their comments.

Keywords Data collection · Inquiry · Environmental educators training · Online teaching

✉ Francisco-José Castillo-Hernández
fch123@ual.es

María-Rut Jiménez-Liso
mrjimene@ual.es

Digna Couso
Digna.Couso@uab.cat

[1] Department of Education, University of Almeria, Almeria, Spain

[2] Department of Mathematics and Science Education, Autonomous University of Barcelona, Barcelona, Spain

Introduction

The inquiry based teaching approach requires students to express their personal ideas, consider the different views of their colleagues when facing a question-problem that engages them (Jiménez-Liso et al., 2019) and to be actively involved in the verification process, that is, in searching for evidence to accept/reject their ideas. This latter step often requires designing, adapting and/or evaluating experimental designs to collect, express and transform information in texts that, in light of explicative models, make it possible for us to express substantiated conclusions.

Given the dialogue and communication-based nature of scientific practices such as inquiry, it would be logical to imagine that their development is boosted within in situ teaching environments and is complicated in distance learning environments, such as online teaching. We drew attention to this point in previous investigations (Romero-Gutierrez et al., 2016; Romero-Gutiérrez et al., 2018), where we developed an inquiry-based teaching approach in a joint online/onsite master's degree that was taught simultaneously at seven universities. In these articles, we studied the effectiveness of student comprehension of the inquiry-based teaching approach experienced. To do so, the characteristics of inquiry spontaneously referred to by the students in their online class diary were analysed. The results showed that the inquiry characteristics most commented on were two-fold: firstly, the need to ask questions and, secondly, the need to use models to describe, explain and predict phenomena. The other characteristics of inquiry went practically unnoticed, particularly in terms of a lack of comments on the analysis of data and search for evidence stages (Romero-Gutiérrez et al., 2018). These absences caused us to think that amongst the possible reasons behind the distance and online teaching effect were difficulties such as not being able to undertake inquiry in situ and communications problems between venues.

To alleviate these possible causes, we considered that for subsequent academic years an improvement would be for students to have first-hand experience of a complete inquiry-based teaching and learning sequence focused on living things (Martínez-Chico et al., 2020). For this experience, as well as asking students the question and allowing the expression of personal ideas via the online teaching system, we gave time for them to suggest experimental design proposals. We then assessed the viability of these proposals and selected one that would allow for in situ data collection, despite the distance, with a data registration system that could be retransmitted live to all teaching sites. The analysis of the data obtained in real-time allowed for a joint analysis in light of the explicative model of living beings to collaboratively draw conclusions.

In this sense, the research objective of this paper is to analyse how the introduced improvement (experiencing a complete inquiry-based learning cycle with particular emphasis on real-time data collection) affects student perspectives on the inquiry-based teaching and learning approach. To this end, we compared the communicative quality of the participants' comments in their online class diary forum during the initial and improved editions of the distance learning course.

Table 1 Types of ICTs according to their teaching goal

Name	Objective
Animations	Visualising dynamic images of systems or processes
Simulations	Showing images of phenomena and interacting with them
Computer modelling	Creation of an explanatory model of phenomena via images or symbols by students
Video-based laboratory	Reproducing previously-recorded movements on screens
Data registration systems	Gathering and presenting data of phenomena in real time

Theoretical framework

The theoretical framework providing the grounds for this study relates to the main aspects of the educational improvement analysed, centred on the use of real-time data registration systems and inquiry-based teaching. Furthermore, for the analysis of data, which allows for comparing the online forum in the initial and improved interventions, we will construct a reference framework for the communicative quality of student comments.

Real-time data collection

The use of Information and Communication Technologies (hereinafter ICTs) in science education is a consolidated fact, justified from a socio-constructivist perspective (Grimalt Alvaro, 2015), as, amongst other factors, they are present in all areas of society. It is necessary to point out that despite the captivating nature of their visual attractiveness and novelty, their employment in itself is not going to produce improvements in science teaching (Jimoyiannis, 2010; Osborne & Hennessy, 2003; Valiente, 2010). We must promote their use depending on their relevance and potentiality (López et al., 2017). Taking this into account, an awareness of the range of ICTs available according to their didactic capacity (Table 1) is necessary for educators in general and science teachers in particular (Pintó et al., 2010).

From these available options (Table 1), in this investigation we focus on real-time data registration and representation or MBL (microcomputer based laboratory) systems, given that the improved teaching situation focused on making the data collection and analysis process more genuine and experiential to participating students by employing this type of tool (MBL or real-time sensors, Fig. 1). The additional software in MBLs allows data representation, in graphical form or numerical tables, while the phenomenon being studied is taking place. That is, they simultaneously allow the observation of the phenomenon and one or more of its variables to be registered. In addition, the real-time sensors or MBLs provide instruments to carry out predictions (i.e. drawing an expected graph) and to do analysis, such as change of scale in graphs and selection of specific data (Pintó et al., 2010).

This ease of collecting and representing data in real time makes MBL sensors extremely useful for developing scientific practices in the classroom, specifically

Fig. 1 Image of the online teaching systems during data collection (centre screenshot in upper row) and five of the teaching sites

relating to the inquiry-based teaching approach used in the online teaching studied here (Romero-Gutiérrez et al., 2018). The main reason is the notable reduction in the data collection and treatment time, allowing more scope for the prediction of results and interpretation thereof (Pinto, Pérez and Gutierrez 1999). This allows students to become more actively, genuinely and significantly involved in inquiry.

Inquiry-based science teaching.

Given the polysemy of the term *inquiry*, it is necessary to include it within the range of possible existing terms. Of the possible meanings for *inquiry* put forward by Barrow (2006) and National Research Council (1996, 2000, 2012), in this article we adhere to the third meaning, that is, as a teaching approach (Couso, 2014). This Inquiry-Based Science Education (hereinafter IBSE) approach allows students to develop the other two important aspects of inquiry. On the one hand, they participate in epistemic practices (Jimenez Aleixandre, 2012; Kelly, 2008), learning through a dialogue and social-model construction process based on inquiry-obtained evidence, in the same way scientists go about their work. On the other hand, they develop a group of specific skills to create evidence on which to base their conclusions, fostering a greater engagement in science by students (Chang, 2013; Gillies & Baffour, 2017). This has linked IBSE to deeper and more significant learning.

Despite the existence of a multitude of ways of organising and understanding this teaching approach (Pedaste et al., 2015), in our proposal (Jiménez-Liso et al., 2019) we consider inquiry as a teaching approach consisting of tasks (in green boxes for the modelling stage and orange boxes for the inquiry stage, Fig. 2) that pursue concrete instructional objectives (in white ovals). The process starts out with a question that engages the students (green and orange box 1, white ovals 1 and 4); ideas are expressed or hypotheses are put forward via a student–student or student–teacher dialogue process (green box 2 and white oval 2; orange box 7 and white oval 5); designs are planned (orange box 8 and white oval 6) that allow the compiling and expression of data (orange box 9 and white oval 7); evidence is sought from the gathered data, allowing students to accept or reject their initial hypotheses; and a number of specific conclusions are reached (green and orange box 10 and white oval 8), to develop a consensual model (white oval 8) that serves to transfer it to new contexts (green boxes 11 and 12, white oval 9). The descriptive knowledge developed during the inquiry stage (in orange) allows for interventions in the phenomenon studied and is essential, via a modelling phase (in green in Fig. 2) to facilitate the building of interpretive models with which the modelled phenomena can be explained (Garrido & Couso, 2017). In addition to this, some authors consider that self-regulation processes should also be taken into account and incorporated into the instructional sequence (Frisch et al., 2018).

The inquiry sequence (Martínez-Chico et al., 2020) summarised in Fig. 2 has been developed by both teachers, with differences in time dedicated to each stage in the two interventions (initial and improved) analysed in this article. We have, from the inquiry stages, created a systemic network of categories with which to carry out the analysis of the participants' comments on the online forum in the initial and improved interventions.

Online forums as learning or learning assessment tools

The tools for interactive online discussion between students and teachers create a dialogue-based space where barriers between education both in and outside the classroom become permeable (Kleine et al., 2019 s. f.), which creates a greater temporal space to reflect on what is worked on in the classroom and the development of higher-order thoughts (Kwon & Park, 2017). These discussions, which are generated amongst equals (Martinez-Villar et al., 2016; Mokoena, 2013), could serve both to improve the educational action itself and to verify the level of fulfilment of the educational objectives put forward, thus determining the level of return on the investment made (Rubio, 2003).

Due to online discussion tools having become a common resource in both in situ and distance learning over the last decade, teaching research has endeavoured to analyse them. This has led to the appearance of many articles of a scientific nature, in which different aspects of these interactions are studied, which we may classify in the following:

1. Articles that study elements that foster greater participation in online forums (Dubuclet et al., 2015; Hew, Cheung and Ng, 2010),
2. Articles that compare the impact of student participation in online forums with their academic performance (Wikle & West, 2019),
3. Articles that study the influence of specific factors (facilitators) in knowledge building (Dubuclet et al., 2015; Hew & Cheung, 2011; Jin & Jeong, 2013), in level of commitment (Jin & Jeong, 2013; Zhu, 2006) or in students' own discourse (Kwon & Park, 2017),

4. Articles that study the nature of comments in order to attract greater participation and interest (engagement) between students, and for the production of deeper learning (Guan et al., 2006; McCarthy et al., 2010; Zhu, 2006)
5. Articles that evaluate the learning level of users in accordance with the quality of their comments, in relation to the knowledge that is the object of study in the course (Jin & Jeong, 2013; Nandi et al., 2012).

All of the above articles have different methodological aspects, but present discourse analysis as a common methodological framework (Cohen et al., 2018) where categories created by the authors are used (Guan et al., 2006; Kwon & Park, 2017; Nandi et al., 2012) or taken from others (Dubuclet et al., 2015; Hew & Cheung, 2011; Hew et al., 2010; Jin & Jeong, 2013; Zhu, 2006). In our case, we share the focus of the first types of studies that endeavour to evaluate learning articulating some measurement of quality thereof.

Therefore, to characterise quality in learning terms, it is useful to speak about the level of depth with which users refer to the knowledge that is the object of learning on the forum, that is, to the knowledge of inquiry-based science education. Inspired by the idea of evaluation rubrics, which are evaluation and research instruments that assign different levels of quality to student production (Dawson, 2015), we assigned different levels of depth regarding knowledge of the IBSE approach exhibited. In order to establish these levels, we take into account the framework of cognitive-language skills (Izquierdo & Sanmarti, 2000) understood as competencies relating to linguistics and that are thought to be necessary for producing different text typologies beyond mere literal or declarative repetition. Due to the fact that each science has its own forms of reasoning and expression (Lemke, 1990) we are interested in cognitive-language skills linked to the sciences, including capacity to describe and/or define, as well as scientific justification and argumentation (Izquierdo & Sanmarti, 2000). In addition, the same authors have used the idea of different reading levels put forward by Wilson and Chalmers (1988, in Sarda et al., 2006) to characterise the types of demands on students in the face of scientific texts. They differentiate between literal demands or questions, which reproduce read and learnt content; inferential questions, which cannot be answered from literal reading and learning and require the application of prior knowledge; and creative and evaluative questions, which demand different levels of transfer of what is read and learnt.

Methodology

Context of the study

In this study we focus on the master's course *Inquiry-based teaching approach for Environmental Educators* which is taught via online teaching simultaneously in seven university sites in Andalusia (distance between the furthest 1000 km and 500 km the closest), using *Adobe Connect*™ and an online platform (Campus Virtual via *Moodle*™, Romero-Gutierrez et al., 2016). This course has seven in situ sessions of four hours each (28 h, 4ECTS[1]) which start with a debate on the objective of scientific education for environmental educators (session 1) where doubts are raised about traditional science teaching to promote the inquiry and modelling-based teaching approach (session 2).The following five sessions summarise these approaches in various specific topics (living being-germination, water cycle, energy efficiency) to finish with a review of what was learnt and felt during the classes (session seven). All of the master sessions are recorded by the online teaching system (*Adobe Connect*™) in a way that if students are unable to watch them live, they can see them recorded and carry out the tasks a posteriori (on the *Moodle*™ platform). These recordings have served as data for our study, as they have enabled us to visualise them, describe them and select those most suited to our objectives.

At the end of each of the seven sessions, the students commented on the *Class diary* online forum about what they thought of the session in terms of what they had learnt, what stood out and how they had learnt. This was done voluntarily and without a fixed time period, generally taking place before the following session. From the moment the course was presented, students were aware of this tool and of the intention to use it as part of the summative evaluation additional to other graded, compulsory tasks in order to pass the subject.

In the initial instruction, analysed in another publication (Romero-Gutiérrez et al., 2018), the inquiry-based teaching approach was presented by the teacher, who gave, as an example, the inquiry sequence beginning with the question: *Is a chickpea a living being?* (Fig. 2) (Martínez-Chico et al., 2020). In this intervention the teacher focused on the responses from the students in each centre to the initial question but stated how the remaining inquiry stages would be carried out with Primary Education students (6–12 years). She thus explained that once students express their ideas responding to an initial question they would have to create, adapt or evaluate a design with the aim of accepting or rejecting the ideas they had previously explained, making specific references to the design to implement. In this case, this involved putting chickpeas into a hermetic container and measuring CO_2 and O_2 via the corresponding MBLs. After this, she showed the graph with the CO_2 and O_2 data, analysed them and explained that the chickpea breathes by absorbing O_2 and expelling CO_2. Finally, she concluded by linking with the living being model, which is formed of vital functions plus autonomy.

In the following academic years (16/17 and 17/18), during the improved teaching intervention, besides stopping to focus on the chickpea question and on the expression of ideas (as in the initial intervention), the teacher also dedicated time to the proposal of experimental designs in the different sites and their evaluation in order to accept a viable option. In addition, she shared the process of real-time data collection using MBL sensors connected to the online teaching platform. The previously obtained data were then analysed and contrasted with their initial predictions and ideas. Finally, and with the participation of all of the centres, the ideas from the living being model were used to interpret the results.

[1] ECTS: European Credit Transfer and Accumulation System.

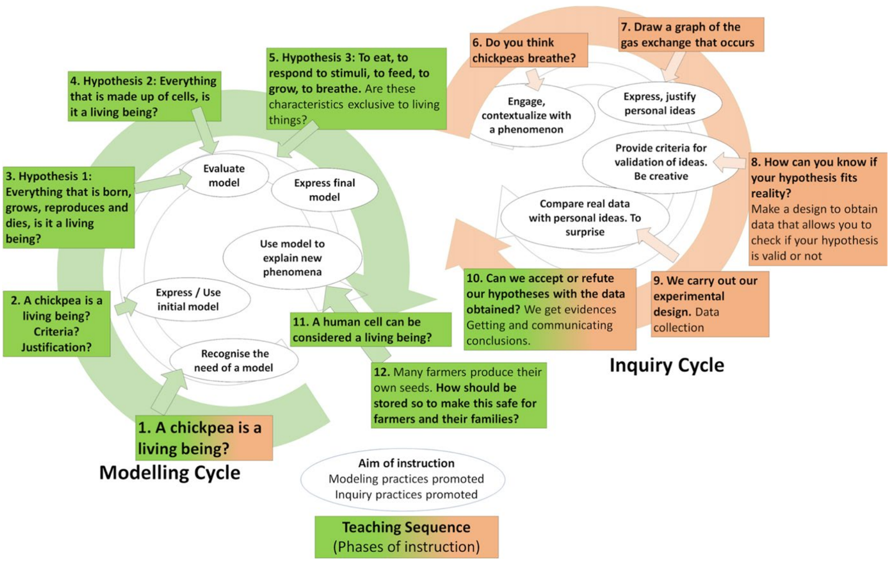

Fig. 2 Inquiry cycle (colour orange, adapted from Jiménez-Liso et al., 2019) connected to modelling cycle (colour green, adapted from Garrido & Couso, 2017) (Color figure online)

Table 2 Stages of inquiry explicitly developed each academic year

Inquiry	Initial instruction	Improved instruction
Initial question: Is a chickpea a living being?	YES	YES
Expression of ideas	YES	YES
Developing designs	NO	YES
Collecting and expressing data	NO	YES
Searching for evidence	NO	YES
Obtaining conclusions and communicating them	NO	YES
Building a model	NO	NO

In order for the creation of designs and collection of data to acquire greater meaning for the students, we set them an activity in which they were required to express their personal ideas in the form of hypothesis and predictions through graphic language, in this case on the phenomenon of the chickpea breathing. In this manner, they put forward three main responses:

- *It does not breathe* and, as such, the graph will stay continuously at 0 (the majority of students favoured this option).
- *It breathes like plants*, that is, CO_2 will drop and O_2 will rise (the majority response amongst those who stated it breathes).

Table 3 Time dedicated to each aspect of the inquiry

Category	*Initial instruction (hh:mm:ss)*	*Percentage of total time*	*Improved instruction (hh:mm:ss)*	*Percentage of total time*
Initial question	00:03:02	5.5	00:06:11	5.1
Expression of ideas	00:30:28	55.4	00:56:12	46.6
Developing a design	00:03:13	5.8	00:18:51	15.6
Collecting and expressing data	00:02:23	4.3	00:07:37	6.3
Searching for evidence	00:03:31	6.4	00:09:20	7.7
Obtaining conclusions	00:04:47	8.7	00:09:04	7.5
Modelling	00:07:36	13.8	00:13:27	11.1
Total	00:55:00	100	02:00:42	100

- *It breathes like animals*, that is, CO_2 will rise and O_2 will drop (the extreme minority response but put forward coherently in the face of the possible options).

In situ and real-time data collection produced a lot of surprises amongst the students and there was conflict with those initial ideas. This conflict was subsequently used to present, without carrying out the complete modelling cycle, the main ideas

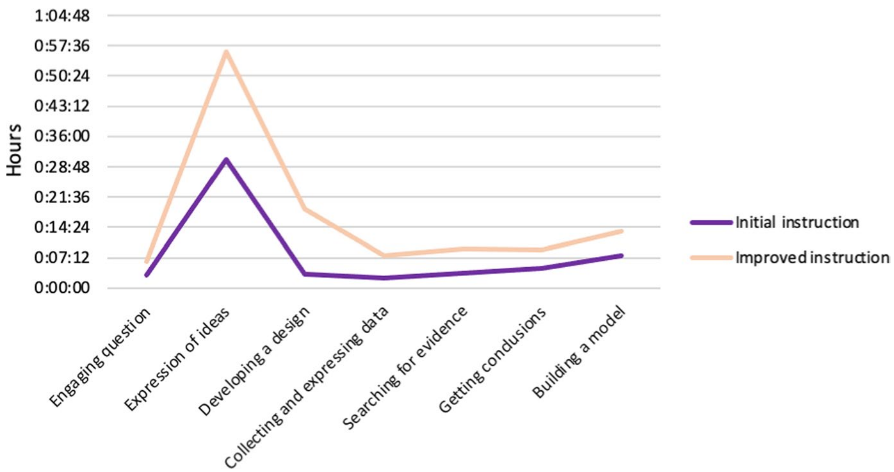

Fig. 3 Implementation times for each inquiry stage in initial (purple) and improved (orange) instructions, data from Table 3 (Microsoft Excel) (Color figure online)

of the model of the living being applicable to the chickpea: vital functions, physiology, and autonomy.

In Table 2 we show the differences between the inquiry stages present in the initial and improved teaching interventions.

In Table 3 (Fig. 3) we show the time dedicated to each inquiry stage in the two interventions. We have indicated those inquiry stages that were narrated by the teachers in grey and those that the students had the opportunity to explicitly experience in white (Table 2). However, as the table is presented, the inquiry stages that were narrated by the teachers are not shown in grey and those that they actually experienced first-hand are not shown in white.

Figure 3 clearly shows that the times dedicated to the initial implementation were decidedly shorter for the improved implementation given that, save for the planning of the initial question and the expression of ideas, the rest of the inquiry stages were only narrated. However, despite the improved implementation, stopping to focus on the proposal of a design and the search for evidence, the advantages of data collection with an MBL system in real time mean that these stages do not take up too much time in relation to the total in the improved instruction. In fact, by creating a graph on how the chickpea breathes (in the event this occurs) in parallel to the collection of data, this process only took five minutes more than narrating it.

Research questions and objectives

The objective that has guided us during this exploratory study has been to analyse the effect of the improvements introduced to the communicative quality of the discussion on inquiry, present in the participants' comments on the online forum. Specifically, we asked whether experiencing the collection of data in real time, and their analysis for seeking evidence that confirms or rejects the initial ideas, affects the communicative quality of their comments in the online *Class diary* forum. To this end, our research questions are as follows:

- What difference is observed in the quality (level of depth) of the comments on the online forum from the initial to the improved implementation?
- How do the teaching improvements, consisting of making it possible to experience the complete inquiry sequence, dedicating time towards students searching for evidence, and collecting data in real time, have an effect on students' awareness of these inquiry stages via their online comments?

Participants

The *Inquiry-based teaching approach for Environmental Educators* master's was taught by two teachers: the initial implementation teacher was an expert with over 20 years of experience and five years of experience in this course via online teaching. The teacher of the improved intervention had six years of experience and it was the first time she had taught this course in the online teaching format. Both teachers, in coordination, implemented the same material and maintained a similar role in the online *Class diary* forum as non-participant observers, as it was a tool self-managed by the students themselves. At the end of the session, the teachers proposed that one of the sites become responsible for starting the Class diary forum, and the students agreed on which student would start it the following day. Afterwards, the other class members participated in promoting the collective construction of knowledge.

In total, for the session dedicated to the chickpea, 50 students took part in the initial intervention and 79 in the improved one, contributing with a single message each ($N_{\text{total messages}} = 129$). The students comprised 86 women and 43 men. Twenty percent came from science degrees, such as physics, chemistry, biology, and environmental sciences, whereas the remaining 80% came from degrees related to education, such as Early Childhood and Primary Education, or General Pedagogy.

Data collection and analysis

To reach the objective indicated in previous sections, an analysis of the written discourse in the students written contributions to the online *Class diary* forum was carried out. Discourse analysis is a process that is systemic in nature and strict in the sense that it examines, analyses and infers the meaning of the written discussion in the context in which it is written for the participants, focusing both on the meanings and the form of the written text (Gläser & Laudel, 2013, as cited in Cohen et al., 2018).

The analysis was carried out following the stages indicated by Denscombe (2014). Firstly, we selected the 129 comments from the chickpea session as a specific sample for the analysis. Secondly, we separated the original text into smaller units, first into sentences and then into units that made sense, for example segments of sentences situated between various commas. Thirdly, we developed the analysis categories. In this case, we carried out the analysis using a double categorisation system oriented towards two aspects: what is said, in terms of the identification of the stages of the inquiry-based teaching approach student comments reference; and how it is said, in terms of the evaluation of the communicative quality with which these stages are referenced.

The categories corresponding to the analysis of the content of the interventions are deductive in nature, as they coincide with the pre-set stages of the inquiry cycle themselves (Fig. 2). The next step we carried out was a coding of the references to inquiry made by the students, taking into account the following aspects: (a) proposing an engaging question; (b) expressing ideas; (c) developing a design; (d) gathering and expressing data; (e) searching for evidence; (f) obtaining conclusions; and (g) building a model (widely developed in Jiménez-Liso et al., 2019).

For the coding of the quality in terms of depth of the references to inquiry, adhering to the idea of rubrics for research (Dawson, 2015) and the reference framework of cognitive-linguistic skills (Izquierdo & Sanmarti, 2000), five levels of depth have emerged in an inductive manner from the data analysis (Cohen et al., 2018). These levels highlight the different degrees of sophistication of student comments in relation to the stages of inquiry. Level zero, which we have called *empty,* refers to the

Table 4 Systemic analysis network of comments on the forum

Levels	Categories	Initial intervention (15/16)	Improved intervention (16/17 and 17/18)
Level 0 *Empty*	Comments with no reference to inquiry	[…]I consider a change of mentality in the teaching practice, which previously goes through a curriculum created with more "common sense" and with a commitment to critical, reflexive, practical, investigative activities that awaken student interest, which is how one truly learns	In the improved intervention there are no comments that mention any aspect relating to the inquiry stages
Level 1 *Declares*	Engaging question	Specify and simplify information: ask the question (teacher)	For us, as educators, asking a good question is crucial for working under inquiry […]
	Expression of ideas	The objective of this methodology is for the teacher to help students to outwardly express all of their ideas […]	[…] at first it was very important to show what conceptions we were presenting […]
	Developing a design	[…]a study is designed […]	[…] we have carried out an experimental design […]
	Collecting and expressing data	[…]data are collected […]	This process encourages people to collect data […]
	Searching for evidence	[…]put their ideas to the test […]	[…] searching for evidence […]
	Obtaining conclusions and communicating them	[…]obtaining conclusions […] and lastly, communicating and sharing ideas	[…]which would bring us to a conclusion […]
	Building a model	[…] through it we could arrive at scientific models […]	[…] from the sequence of questions asked by the teacher, we have been able to build a living being model […]

Table 4 (continued)

Levels	Categories	Initial intervention (15/16)	Improved intervention (16/17 and 17/18)
Level 2 *Describes*	Engaging question	For this I think that from a well-chosen question that motivates the students and is appropriate for their level	[…] we must not just ask indirect questions related to their context, but ones that ENGAGE
	Expression of ideas	No comment exists in this regard in the initial intervention	One of the things that I liked most about this process is that in each centre, in each individual, even, while we answered one question or another we also had to find a way to explain it to the others. That is, it wasn't enough to answer with what we ourselves thought about those questions, rather, we were also required to explain ourselves so that our colleagues were able to understand it, and even convince them
	Developing a design	No comment exists in this regard in the initial intervention	No comment exists in this regard in the improved intervention
	Collecting and expressing data	No comment exists in this regard in the initial intervention	No comment exists in this regard in the improved intervention
	Searching for evidence		It is a tool for seeking evidence that allows us to contrast ideas […]
	Obtaining conclusions and communicating them	No comment exists in this regard in the initial intervention	No comment exists in this regard in the initial intervention
	Building a model	[…] building criteria in a consensual and substantiated manner […]	[…] we have established a series of criteria that we have evaluated at the end […]

Table 4 (continued)

Levels	Categories	Initial intervention (15/16)	Improved intervention (16/17 and 17/18)
Level 3 *Identifies*	Engaging question	Although we've spent three hours investigating whether a chickpea is a living being […]	Amongst the questions the teacher proposed are: Is a chickpea a living being? What criteria do we use to describe a living being? How would we justify it?
	Expression of ideas	The problem here is that nobody knows for sure what life is. We find ourselves perhaps at this boundary line spoken about in class, but the truth is that life is a concept conceived in light of our own inability to stop categorising reality. Nobody agrees on this because at the moment it is only a point of view (there is no consensus on whether, for example, viruses are life forms or not)	In my site it was also divided 50% between yes and no. I answered no, given that if I based it on my acquired conceptions the chickpea doesn't fulfil the characteristics of a living being (but inside I was thinking it must be because it's a seed and produces life)
	Developing a design	No comment exists in this regard in the initial intervention	With measurers of CO_2 and O_2 percentages. To put it into practice we're going to use two sensors, we put the chickpeas into a closed plastic receptacle, and measure their CO_2 and O_2 consumption values
	Collecting and expressing data	No comment exists in this regard in the initial intervention	[…] was being able to observe in situ how they respired […]
	Searching for evidence	No comment exists in this regard in the initial intervention	We compared a chickpea, knowing what it is, with something we don't know. We need more specific criteria to know what to put into the living beings category and what not to put. We're going to compare a chickpea with a chicken, both are related, they're made of cells, etc We're going to compare living things with non-living things, and we're going to focus on whether a chickpea fulfils all of the points we've mentioned Examples have been given on how to check if it has cells (with a microscope) and if it respires (placing it in a glass with a candle to verify that the chickpea doesn't have oxygen)
	Obtain conclusions	Experiencing the inquiry process from within helped us realise that, effectively, it wasn't an inert being	[…] and in this way it was demonstrated that the chickpea respired and therefore the hypothesis that the chickpea didn't respire had to be rejected

Table 4 (continued)

Levels	Categories	Initial intervention (15/16)	Improved intervention (16/17 and 17/18)
	Building a model	No comment exists in this regard in the initial intervention	For this we can base ourselves on functional criteria and state that all living things fulfil the functions of nutrition, relation and reproduction. We can also use a structural criterion and say that living things are formed by cells, which are the basic functional and structural units we study in biology. There are also latent life forms that need certain environmental conditions to activate their metabolism
Level 4 *Transfers*	Inquiry cycle	I have precisely just begun a process of this type. We were (1st year of Compulsory Secondary Education) studying minerals and rocks, analysing collections, mineral properties, different types of rock, etc. via direct observation. Questions immediately began to arise. Suddenly, a shy and introverted girl raised her hand, and I obviously gave her priority. Her grandmother lives in Moropeche, a little town in the Sierra de Alcaraz mountains, and on their walks she had observed something she thought amazing and which unsettled her. How is it possible that there are sea fossils on the top of mountains over 1000 m high? I soon realised (I had gone back over the subject in my Master's) that it was a key question, via which we could arrive at scientific models that explain the formation of rocks, plate tectonics… So they've just made their hypotheses and now it's time to investigate. We also have a visit to Terreros planned very soon (*Let's look after the Coast* Programme), where they can discover evidence to justify their hypotheses, because there we can observe different rocks, volcanic formations, mini folds, mini faults, mini deltas and mini lagoons	Before this subject we had already dealt with the importance of beginning the construction of knowledge with alternative ideas and, just the next day, speaking about it in class I started to put it into practice. I was explaining the meaning of sight and it was fantastic. I began with the question 'Why do we see? What do you imagine your pupil is and why is it black?' and 'How do you think we fit all of those images into something as small as the pupil?' It was so much fun, students gave 200%, even those who don't normally participate, they all wanted to give their opinions on the topic, and I even found it difficult to moderate their turns. All of the answers were written on the blackboard for later discussion and I started to understand a number of things like losing control of the class so that the students could be the protagonists, and not being able to respond to all of the doubts, because the students were asking questions in parallel and you don't always have an answer. But the best of all was when I said time was up and that we'd continue another day. It had flown by and they didn't want to stop taking part. I left really satisfied, what a change. My history teacher colleague who went after me commented in the staffroom "I don't know what you did to them but it took me ages to quieten them down enough to give my class", and that "my class" made alarm bells ring, because it's not our class, it's the students' class, everyone's class

comments that fail to mention any aspect relating to the inquiry stages (e.g. general comments on the subject, to the group, etc.); level one, *declares*, classifies those comments which only mention the name of a stage of the inquiry cycle in a completely literal fashion, or make a similar reference; level two, *describes*, covers those comments that describe the inquiry cycle stages in a way that indicate the qualities that the stages in question must present; level three, *identifies*, refers to comments in which students undertake an inferential activity, and are able to identify with examples the stages particular to inquiry; lastly, level four, *transfers*, alludes to comments in which knowledge acquired on the inquiry stages is extrapolated to other contexts, such as examples taken from teaching experiences or related to those prior to the subject. With the objective that the reader can more easily understand the categories and levels presented here, in Table 4 we show the systemic network of discourse analysis of the *Class diary* forum with examples of written production by participating students that we consider characteristic of each category and level.

The messages from the students in the *Class diary* forum were analysed (Cohen et al., 2018) using the systemic network designed (Table 4) with the aid of the ATLAS.TI (v.8) program. To guarantee accuracy and objectivity throughout the process, two researchers carried out the coding independently. From this point a 92% consensus was obtained, which brought them to a process of debate and reflection to reach consensus on those comments in which there was disagreement. In the same way, and to give interpersonal and temporal validity to the categorisation (Vazquez & Angulo, 2003), the researchers repeated the process four months later, without detecting any significant variations.

As a fifth and final step according to Descombe (2014), we counted the number of comments in each of the inquiry categories together with the level of sophistication in terms of communicative quality (Table 5).

Results and analysis

In order to obtain a clear vision of the results obtained in the sophistication of communicative quality of the comments from the students before and after applying the improvement, we show the general results achieved following the coding of the online forums (Table 5). Initially, we consider the frequency of the comments coded in each category by academic years (15/16, 16/17 and 17/18) as a format of expression of the results. The comparison between the two years in which the improvement was included (16/17 and 17/18) did not provide us with any information whatsoever, so we decided to group both years together (N = 79) to compare them with the results from the initial intervention (15/16, N = 50). For their comparison, in Table 5 we have put the percentage of comments from each category, whether from the initial or improved intervention. In this manner, the Fig. 32% of students in level 3 of the *Initial question* category in the initial intervention was obtained by dividing the frequency of 16 comments by 50 and then multiplying it by 100.

Therefore, Table 5 shows three variables: in the upper part two columns appear for each category where it is indicated whether it is the initial intervention (I in

Table 5 Percentage of comments at each inquiry stage in the initial (I, columns in purple) and improved (M, columns in orange) instructions (own production) (Color figure online)

		Initial (I) and improved (M)													
Levels		I	M	I	M	I	M	I	M	I	M	I	M	I	M
4	Transfers	(I) 0.07 (M) 0.36													
3	Identifies	12	**60.76**	2	27.85	0	2.53	2	1.27	0	13.92	2	26.58	0	18.99
2	Describes	**32**	36.71	6	16.46	0	0	0	0	4	3.8	0	0	2	7.59
1	Declares	18	40	**20**	**98**	**2**	**8**	**4**	**6**	**8**	**54**	**12**	**48**	**8**	**44**
0	Empty	(I) 8.29 (M) 0													
		Engaging question		Expression of ideas		Developing a design		Gathering and expressing data		Searching for evidence		Obtain conclusion s		Building a model	
		Categories													

purple) or improved (M in orange); in the lower part of the table we indicate the categories used to code the comments from the *Class diary* online forum; and finally, on the left side of the table we have indicated the levels of sophistication of communicative quality used in the coding. Given that at level zero the students do not speak about inquiry and at four they do so generically, they cannot be associated to any category and we have therefore included the percentages obtained in the middle, in grey.

The numbers shown in bold in Table 5 refer to the greater percentage of students that make a comment on each category in each implementation.

Results by categories

If we focus on the reading of the highest percentages of each category in the initial intervention (in bold in Table 5), we observe that the *trigger question* (32%) and the *expression of ideas* (20%) were most relevant for the students, which coincide with the stages of inquiry the students experienced and those the teacher spent the most time on (Table 3). As for the results obtained by Romero-Gutiérrez et al. (2018), the other categories show percentages of little relevance (*obtaining conclusions reaches 12%)* with the categories *developing a design* and *gathering and expressing data* being totally overlooked, obtaining a meagre 2% and 4% respectively.

In the improved intervention, the percentages are much higher in the rest of the categories. Almost all students (98%) made comments on *the expression of ideas* and over half (60.7%) commented on the *initial question*, with the teacher dedicating the most time to both these categories (Table 3). In the improved sequence, where data were collected in real time and time was dedicated to its transformation into evidence, half of the students did widely mention elements related to the categories following inquiry: *search for evidence* (54%), *obtaining of conclusions* (48%) and *construction of models* (44%). This appears to denote that, on experiencing the *search for evidence* and *obtaining of conclusions*, and dedicating more time towards them, these categories stopped going unnoticed by the students, unlike what occurred with the students in the initial intervention.

The categories *developing a design* (8%) and *gathering and expressing data* (6%) were those that obtained the fewest comments in the improved implementation. In this sequence the teacher dedicated 18 min to making proposals on experimental designs, which were quickly evaluated and rejected. This brought her to propose one in which MBL O_2 and CO_2 sensors would be used, which was rapidly accepted by everyone. Perhaps the fact that the designs created by the students themselves were quickly rejected, and that the teacher proposed a valid one, could have led them to interpret this stage as being a mere formality in which the proposal by the teacher is the most important.

One of the substantial improvements of the final implementation was the real-time data collection (developed by the teacher in 7.5 min and retransmitted live in all of the sites). A mere 6% of students commented on this category. This could mean that the improvement failed to produce the desired effect. This would be the case if the comments in relation to the search for evidence had not risen to 54% of students. It seems that they afforded more significance to the evidence (the fact that the chickpea breathes and how it breathes) than the data themselves (% of CO_2 or O_2) which were not used at any point (only the rising or falling graph, respectively).

We can therefore state, in overall terms of comments by categories, that the improved intervention created an effect on the perception of the students in some inquiry stages that had gone unnoticed in the initial intervention, specifically, on the search for evidence.

Below, we are going to analyse whether the improvement introduced had an effect on communicative quality or not, that is, on the sophistication of the comments by the students.

Results by levels of communicative quality

Concentrating on the results by levels (reading of Table 5 by rows), in the initial intervention we see that the majority of the comments on the categories occurred at level 1 (*declares*), with the exception of *initial question*, where the students made more comments at level 2 (*describes*, 32%).

For the improved intervention, the majority of the categories also have higher percentages than in level 1, except for the category on the question (60.7%), situated at level 3 (*identifies*). For example, the discourse went from comments in which it was stated that "*the most important is to start from an appropriate question"*

(E15iniPN1,[2] level 1), to other more specific comments which identify the question: *speaking about science is not just making reference to formulation, the periodic table… it can also be done with the contraction of hypothesis or scientific experimentation: is a chickpea a living being? And a chair? What are the criteria that have been taken into account?…* (E20mejPN3,[3] level 3).

In addition, the tendency to increase communicative quality in the comments of students towards level 3 (*identifies*) was clearly reflected in the rest of the categories, as at this level the expression of ideas categories significantly rose from the initial (2%) to the improved (27.85%) with specific comments such as *in my head there was a mixture of thoughts and doubts, at times I thought that it was a living being because it came from another living being, but later I thought it wasn't because it didn't move or respire…* (E25mejEIN3[4]).

Likewise, although the category *Searching for evidence* did not receive an excessive number of comments (13.92) at level 3 (*identifies*), it served to draw attention to the fact that some students specified the process they followed during the class: *we compare a chickpea, knowing what it is, with something we don't know*. *We need more specific criteria to know what to put into the living beings category and what not to put. We're going to compare a chickpea with a chicken, there's a connection between them, they're made of cells,* etc. *We're going to compare living things with non-living things, and we're going to focus on whether a chickpea fulfils all of the points we've mentioned* (E8mejBPN3[5]). It also specified what the *conclusions* (25.58%) they arrived at were, *after slowly rejecting some of the hypotheses, [the teacher] showed us a* CO_2 *measurer and we were able to verify that CHICKPEAS BREATHE!!!!* (E31mejCN3[6]).

Independently of the value of the percentage for the *building of a model* category (18.99%), which went unnoticed by the students of the initial intervention, in the improved one they endorsed the chickpea as a living being based on key ideas from the model: *some of the basic characteristics for something to be able to be categorised as a living thing are: it must be made up of cells; it must breathe; it relates to its environment; it possesses a metabolism that allows it to process acquired nutrients; it grows and develops; it reproduces,* etc. (E53mejMN3[7]).

These qualitative examples, together with the results of percentages obtained, show that the students in the improved intervention, as well as recognising more of the inquiry stages, are able to identify them and relate them with examples of the experience they went through. In contrast, in the initial intervention, as well as many

[2] E15iniPN1 refers to student 15 of the initial intervention (ini) asking a question (P) at level 1 (N1).

[3] E15iniPN1 refers to student 20 of the initial intervention (ini) asking a question (P) at level 3 (N1).

[4] E25mejEI3 refers to student 25 of the improved intervention (mej) expressing their ideas (EI) at level 3 (N3).

[5] E25mejEI3 refers to student 8 of the improved intervention (mej) expressing search for evidence (BP) at level 3 (N3).

[6] E25mejEI3 refers to student 31 of the improved intervention (mej) explaining conclusions (C) at level 3 (N3).

[7] E53mejMN3 refers to student 53 of the improved intervention (mej) explaining the model (M) of the living being at level 3 (N3).

categories (those not experienced) going unnoticed, the students who do comment on them fail to go beyond a mere literal reference in all of the categories (not experienced), except for the question they did experience and describe (32% level 2).

As a result of all of this, the improvement of having students go through the different stages of inquiry has meant that, in general terms, they are more aware of the stages they have experienced, translating into a notable increase in the diversity of comments in the improved intervention and a positive effect on their sophistication (communicative quality). In particular, the majority of the comments indicate the inquiry stage in quite a literal sense (level 1), but a significant percentage identify specific examples (level 3), not simply conforming to the description of the stages (level 2 being practically absent from the comments).

In short, from these results we believe that the improved teaching provided to our students creates an increase in communicative quality and a greater awareness of the diverse inquiry stages of the IBSE approach.

Conclusions

Online learning can have benefits in terms of engagement, but it could also worsen the quality of the interactions and discussions (Dumford & Miller, 2018). In our case, it was perceived by the students of the joint online/onsite Master's Degree in Environmental Education as one of the greatest weaknesses of the course (Romero-Gutierrez et al., 2016). In this context, inquiry teaching becomes a challenge (Kawalkar & Vijapurkar, 2013), as distance to students impedes the process of interaction and dialogue it requires. In these circumstances, teachers can rely on what the inquiry-based teaching approach consists of with examples or develop it in a guided way (National Research Council, 1996, 2000; Romero-Ariza, 2017). This is done by aiding students in their experience of it and dedicating time to reaching agreements in each site for each stage of the inquiry process. This second option was the teaching improvement implemented, following confirmation that some stages of the inquiry approach went unnoticed when merely describing them, such as the gathering of data, data analysis and the search for evidence, which occurred in the 15/16 academic year (Romero-Gutiérrez et al., 2018). The incorporation of data collection in real time retransmitted live via the online teaching system (Fig. 1) in 16/17 and 17/18 (improved instruction), allowed for the analysis of its influence regarding the diversity of inquiry stages mentioned and the level of depth of the discourse exhibited by the students in the online *Class diary* forum.

The quantitative differences of time dedicated to the teaching of each stage of inquiry (Table 3) in each intervention and, especially, the increase in time devoted to experimental design and in situ real-time data collection, did not suppose an increase in the frequency of comments in these two stages compared to the initial intervention. Notwithstanding, it did mean that many comments at level one (*declares*) were raised to level three in terms of depth (*identifies*), which indicates that upon going through the experience of these stages, the students became aware of the need to verify, and how this evidence supports conclusions.

In this chickpea sequence the specific data (percentages of O_2 and CO_2) are not meaningful for the students, rather its evolution with dynamic graphs produced by the program associated to the MBL sensors helps to set two great personal ideas expressed by them against one another: "*a chickpea is not alive*" (does not breathe) and, for those who did consider it to be so, that it breathes "*like plants: they expel O_2 and take in CO_2*". For the conflict put forward in this latter idea (respiration = photosynthesis) it is necessary to combine this sequence with another that helps to centre photosynthesis on food production rather than gaseous exchange.

With the results of this study we have been able to confirm that to test hypotheses and data gathering first-hand helped to make the comments of the participants more real and specific, making explicit references to what they experienced live and identifying specific cases in each stage, as well as the literal reproduction of what happened in class.

This has implications in terms of integrating ICTs and, in particular, of the data registration system, as it shows the importance of gathering data in real time. In scientific practices involving inquiry (and argumentation) we often offer hypothetical data that is typically provided by researchers or may be taken from the internet with static graphics. We are talking, basically, about pre-recorded results, which will be dependent on the materials and time we have available. These results, however, can lack credibility and limit the engagement of students. This puts us on track for future research in relation to the analysis of the influence of the video-based laboratory or other types of data provided in the face of the data registration system analysed in this paper.

Implications

According to our results, the use of ICTs related to data recording (for instance, MBL) will make students aware of the importance of finding evidence in IBSE, which was one of our objectives after implementing the improved version of the master course. In this sense, the use of ICTs without reflection can carry out a use without any specific purpose, which could cause a lesser effect than the one desired by the teacher. Therefore, so that university teaching is not affected in virtual environments, reflection and analysis of the ICT options are necessary.

On the other hand, the data we obtained seems to indicate that the improvement we proposed in the second year, where the students lived the IBSE approach in full, allowed the students to understand more fully the stages that make up said approach. Despite the singularities of online teaching, that are important to take into account, we consider that in IBSE it is important to translate some of the lively characteristics of the face to face environment to the online one, in order to foster engagement and give authenticity to the study of the real phenomena in online environments. In short, we would like to say that, given the current situation in which the pandemic has led many university lecturers to teach classes online, it is essential to investigate what they are the factors that foster learning in virtual environments.

Limitations

One of the limitations we would like to address refers to the sample. As we already present in the participants section, two teachers and 129 students were the sample we used to reach our paper goals. In order to improve our research and make sure that the results are not consequence of the teachers, we consider it necessary to increase the number of these, as well as groups of students. In this sense, and for the same reason, more sequences with other contents should be implemented, so that we find out the effect of the content on the communicative quality of the discussion on inquiry.

Another limitation refers to the time spent on each of the inquiry stages in initial instruction and improved instruction. As can be seen in Fig. 3 (page 9), improved instruction spends more time on the different stages of inquiry, which could have affected the results achieved. Therefore, we will analyse its influence in more depth in future research.

Likewise, it should be noted that, while the interaction between the different universities took place online, the students who were part of it did so in person. Taking this into account, it would be very interesting to compare the results obtained in this research, in a dual (online/onsite), synchronous (students participate at the same time) and group environment, with a fully online, asynchronous (students can participate at any time) and individual environment.

These limitations put us on track for future research in relation to the analysis of sequences in virtual environments, as well as the consequences of the use of microcomputer based laboratory in such contexts.

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Availability of data and material The datasets generated during and/or the current study (forum and videos) are not publicly available due they are in Spanish but are available from the corresponding author on reasonable request.

Code availability N/A.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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Francisco-José Castillo-Hernández researcher at University of Almeria (Department of Education)

María-Rut Jiménez-Liso senior lecturer at University of Almeria (Department of Education) and principal investigator in Sensoscience research group

Digna Couso senior lecturer at University of Almeria (Department of Mathematics and Science Education) and director of CRECIM (Research Centre on Science and Mathematics Education)