UNIVERSIDAD DE ALMERÍA

ANÁLISIS DE SECUENCIAS DE ENSEÑANZA Y APRENDIZAJE SOBRE EL FENÓMENO DE FLOTACIÓN EN EL MARCO DE LA INVESTIGACIÓN DE DISEÑO

ANALYSIS OF TEACHING-LEARNING SEQUENCES ON THE PHENOMENON OF FLOATING AND SINKING IN THE FRAMEWORK OF DESIGN RESEARCH

Memoria presentada para optar al Grado de

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Doctorando

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Directoras

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A mi madre, Paqui, que me ha ayudado a ser la persona que soy hoy día

A mi padre, José Luis, que me ha enseñado el valor del esfuerzo

A mi hermana, Irene, que es la luz y la inspiración de mi vida

Agradecimientos

¿Y hacer un doctorado no es un trabajo muy solitario? Esta pregunta, surgida de una tutoría con una alumna del Grado de Maestro en Educación Primaria, me pareció tan impactante que he querido rescatarla para los agradecimientos. Muchos de vosotros os preguntaréis por qué he querido rescatarla… ¿Acaso mis cuatro años de Tesis se han caracterizado por la soledad? ¡Todo lo contrario! Sin embargo, esta pregunta me ha servido para cuestionarme a mí mismo: ¿Quién me ha acompañado en estos años de Tesis?

Si pongo la mirada en el pasado, es inevitable acordarme de María Martínez Chico. Tú fuiste mi primera profesora de Didáctica de las Ciencias Experimentales y la que, sin duda alguna, marcaste un antes y un después. Tus clases eran una montaña rusa de emociones… Inseguridad (cuando tenía que explicar por qué cambiaba el número de horas de luz solar), interés (quería saber sí o sí el porqué de la variación del número de horas de luz solar), confianza (en el momento en el que mi cabeza hizo *click* y entendí el modelo), pero, sobre todo, si tengo que destacar un estado emocional en tus clases, sería el enganche. María, tengo que agradecerte enormemente la experiencia que me hiciste vivir. Sin ella no estaría donde estoy hoy.

Tras haber experimentado en primera persona las clases de Didáctica de las Ciencias Experimentales, sabía que quería enseñar como María me había enseñado a mí, pero quien me mostró el mundo de la investigación fuiste tú, Paco Gil. Trabajar contigo fue una casualidad, pues no estaba en mis planes… Pero cuán agradecido estoy por esa casualidad. Fueron muchas mañanas trabajando codo con codo en tu despacho, aprendiendo de ti, de tu experiencia, pero sobre todo, tengo que agradecerte que estuvieras a mi lado en un año muy intenso en lo personal, ayudándome en todos los momentos de agobio y angustia con una sonrisa en la cara. Gracias Paco.

También quiero mencionar a Ana Belén Montoro, que, pese a los difíciles momentos que estábamos pasando, no solo me acompañaste de forma incansable en mi Trabajo Fin de Máster, sino que te convertiste en un verdadero apoyo. Todas las reuniones online que hicimos, los viajes a Granada para tutorías y muchas más experiencias a tu lado me han permitido conocer a una persona maravillosa, trabajadora, humilde y, por encima de todo, buena. Gracias por estar ahí, Ana.

En esta época (tras hacer el máster en investigación y trabajar como técnico de apoyo a la investigación) había una pregunta que me rondaba en la cabeza de forma continua: ¿Qué hacer con mi futuro? Aquí entró en escena una de mis directoras: Rut Jiménez Liso. Ya en el momento en el que trabajaba con Paco me enviaste varias tareas (por ejemplo, recortando vídeos o contabilizando tiempos en los mismos) y, precisamente, fueron las mañanas que eché viendo vuestros vídeos (los de Sensociencia) con niños de Primaria y/o Secundaria cuando empezó a rondarme una nueva idea en la cabeza: quizás esto de la investigación no esté tan separado de lo

que a mí me gusta, que es enseñar y estar pegado al aula y, por tanto, podría dedicarme a ello. Así, en una mañana de verano (junio de 2018) nos reunimos en tu despacho para hablar de mi futuro y ahí fue cuando vi claro que yo quería enseñar, pero también investigar. Tú fuiste quién me enseñó que una y otra profesión no eran contradictorias… ¡Todo lo contrario! A partir de ese momento, cuatro han sido los años que hemos compartido (aunque espero de todo corazón que sean muchos más), con llamadas diarias, millones de reuniones, aunque también con terapia psicológica. En serio, no he visto persona tan positiva, empática, cercana y humana como tú, Rut, y lo mejor aún es que lo transmites. Además, he de decir que eres la persona que más me ha sacado de mi zona de confort (¿a cuántos retos me habrás hecho enfrentarme en estos cuatro años?), lo que te agradeceré enormemente toda mi vida, pues creo profundamente que han sido los años en los que más he aprendido, tanto a nivel personal como laboral. Gracias, Rut, por todo.

En aquest mateix període també vaig conèixer la Digna Couso, la meva altra directora de Tesis. A la famosa reunió que va tenir lloc el juny de 2018 Rut ja em va parlar de tu i ho va fer en termes extremadament positius. I, efectivament, quan vam tenir la primera reunió vaig poder comprovar que Rut tenia raó. No obstant això, amb les primeres impressions no es pot conèixer una persona. Per això, agraeixo infinitament haver tingut l'oportunitat de treballar quatre anys al teu costat perquè he pogut *vivenciar* en primera persona el teu entusiasme a l'hora de treballar, l'energia que desprens 24 hores 7 dies a la setmana, les ganes d'aprendre de manera continuada, però també la teva insistència en què nosaltres, els doctorands, gaudim del procés. Gràcies, Digna, per tots aquests aprenentatges que m’enduc amb tu.

En definitiva, gracias a mis dos directoras por haberme acompañado en este camino. Con vosotras a mi lado nunca me he sentido solo y, lo más importante, siempre me he sentido apoyado y valorado.

Por supuesto, no puedo dejar de hablar de Rafa López-Gay. Muchas conversaciones son las que hemos mantenido, ya sea en el despacho del Edificio Central, en los trayectos de casa a la universidad y, en este último año, después de tus clases sobre flotación y hundimiento de objetos. Los mayores aprendizajes que me he llevado contigo han sido, por un lado, la generosidad (siempre has estado ahí para ayudar en todo lo que se necesitaba) y, por otro lado, la importancia de establecer un vínculo con el alumnado. Te he visto dando clases y haciendo tutorías y, como te he dicho en multitud de ocasiones, me maravilla el vínculo que eres capaz de generar con los alumnos. Los conoces, te interesas por ellos y, como no puede ser de otra manera, acaban confiando en ti, lo que repercute positivamente en la clase. Gracias Rafa.

Como habéis podido observar, he nombrado a tres personas de forma separada: María, Rut y Rafa. Sin embargo, no quería perder la oportunidad de juntaros en un solo párrafo para explicaros lo afortunado que me siento por haber coincidido con vosotros. Sois el mejor regalo que me ha dado el doctorado. Gracias Sensociencia.

Así pues, si hablamos de personas que me han acompañado durante el doctorado, es imprescindible que hable de mi familia catalana de la Universidad Autónoma de Barcelona. Son muchas las personas que conocí allí (Caterina, Anna Garrido, María Rosa, Francisca, Camilo y un largo etcétera). Especial mención quiero hacer a dos personas por la importancia que han supuesto para mí:

Èlia Tena, quantes vivències hem viscut i experimentat junts malgrat conèixer-nos només des de fa quatre anys… Des de compartir despatx al CRECIM (amb el meu famós *fins demà noies*), passant per unes vacances conjuntes a Almeria (per descomptat, ensenyant-te a tu i a Ferran el que és de veritat *tapejar*, però també les platges paradisíaques del Cap de Gata) i fins i tot videotrucades (que hem titulat *Write the tesis with me*) per acompanyar-nos en aquests darrers moments de tesi. Èlia, tu no ets només una companya de doctorat, tu ets la millor amiga que podria tenir. No se m'oblida que tenim molts projectes de futur conjunts, destacant per sobre de tot el nostre canal de Youtube. Gràcies Èlia.

Miquel Pérez, tú me has acompañado incluso desde antes del comienzo de mi Tesis, concretamente desde aquel curso de formación de profesores en Madrid. Has estado siempre ahí, en los momentos buenos, pero también en los no tan buenos, aportándome serenidad, tranquilidad, ánimos y, sobre todo, tu cariño incondicional. Tus ganas por vivir millones de experiencias nuevas, por aprender y por ayudar a todas las personas que te rodean han sido una verdadera inspiración para mí. Gracias Miquel.

And if I'm talking about a Catalan family, I can't forget my other Dutch family (Lucy, Nuril, Thomais, May, Argyris, Dangmar, Nelly and Theila). It was only a three-month stay at the Institute for Science Education and Communication, but it was more than enough time to get to know a wonderful group of people with whom I hope to share many moments in the future, whether in the Netherlands, Greece, Cyprus, Spain or any other country. Thank you very much ISEC group.

En el plano personal, quería nombrar en primer lugar a mi familia: mis padres, José Luis y Paqui, y mi hermana, Irene. Vosotros sois el verdadero motor de mi vida. Tantas son las cosas que he aprendido a vuestro lado que, solo de pensarlo, me siento pequeño. Mamá, desde que era un niño solo recuerdo cómo has luchado como una leona por tu familia. Me has llevado a todas las clases extraescolares del mundo, has estudiado conmigo, me has cuidado… Gracias, mamá, por todo lo que has hecho, haces y harás. No podría tener una mejor madre que tú. Papá, en ti siempre he sentido que podía confiar, contarte lo que rondaba por mi cabeza o lo que me preocupaba, porque, si algo te caracteriza, es tu empatía y la confianza que siempre has tratado de transmitirme.

Gracias por todo, papá. Irene, no suelo decirlo mucho en voz alta, pero te quiero por encima de todas las cosas. Tú has sido un verdadero modelo a seguir. Nunca te has empequeñecido ante los difíciles retos que la vida te ha deparado. Más bien al contrario. ¿Qué el reto era difícil? Pues más luchabas. Siempre serás la brújula que guíe mi camino. Mamá, papá e Irene: vuestro ejemplo siempre será un pilar en mi vida.

Tampoco me quiero olvidar de todas mis tías (María José, Belén, Encarni y María Elvira), que han formado parte activa de mi vida. Mención especial quiero hacer a mi tía Encarni y a mi tía María Elvira:

Tita Encarni, qué voy a decirte que no sepas ya… Tú has sido un pilar esencial en mi vida. Desde que era pequeño me has tenido entre algodones (siempre decías que al ser el único niño de todos los primos tenías que mimarme) y, a medida que he ido creciendo, me he dado cuenta de que no podría haber tenido más suerte contigo. Creo que no hay mejor persona que tú en el planeta Tierra. Tus ganas de ayudar a los demás y tu apoyo incondicional durante toda mi vida han significado mucho para mí. Gracias por ser quién eres, tita.

Tita Mari, tú y yo siempre hemos tenido una conexión brutal. Como sabes, desde pequeño siempre he dicho que quería ser como tú y, si lo pienso, sinceramente sigo considerando lo mismo. Para mí eres un ejemplo de mujer. Sé que, pase lo que pase, tú siempre vas a estar ahí, porque siempre serás mi princesa. Gracias tita Mari.

Antes de terminar, quería recordar a mis cuatro abuelos: Antonio, María, Paco y Angustias. Por circunstancias de la vida solo he podido conoceros a tres de vosotros, pero lo que tengo clarísimo es que sin vuestro esfuerzo y tesón no seríamos la familia que somos. Gracias a los cuatro por todo.

Finalmente, quiero recordar a mis amigos más especiales: Sergio y Jonathan. Nos conocemos desde parvulario y, aun así, aquí seguimos. Hemos crecido juntos, aprendido los unos de los otros, nos hemos apoyado en todos los momentos, tanto buenos como malos, pero, lo más importante desde mi punto de vista, siempre hemos estado unidos. Gracias de todo corazón por estar ahí, Sergio y Jonathan.

Resumen

La Tesis Doctoral *Análisis de secuencias de enseñanza y aprendizaje sobre el fenómeno de flotación en el marco de la investigación de diseño* surge como consecuencia del interés y la necesidad de los grupos de investigación Sensociencia (UAL) y CRECIM (UAB) por de diseñar SEAs basadas en indagación y modelización y por reflexionar sobre el proceso que les ha llevado a su diseño. En la presente Tesis Doctoral, siguiendo esta misma línea, pretendemos clarificar cuáles fueron los principios de diseño que nos guiaron en el diseño de nuestra SEA sobre flotación y hundimiento de objetos: *Ni flota ni se hunde*.

Para alcanzar este objetivo, la Tesis Doctoral ha sido dividida en tres estudios con sus respectivas preguntas de investigación. En el Estudio 1 analizamos cuáles han sido las aportaciones que se han realizado desde la literatura didáctica sobre el fenómeno de flotación y hundimiento de objetos. Para la consecución de este objetivo hemos realizado una revisión sistemática, seleccionando 71 artículos de investigación con amplitud cronológica: desde la década de los setenta hasta la actualidad. Esto supuso la generación emergente de un protocolo de análisis y su posterior aplicación mediante la categorización de los artículos relacionados con el fenómeno de flotación y hundimiento de objetos.

En el Estudio 2 realizamos una comparación de cinco secuencias de enseñanza y aprendizaje sobre el fenómeno de flotación con el objetivo de identificar las características más relevantes de cada una de ellas, así como visibilizar la comparativa de secuencias como un recurso previo al diseño relevante tanto para docentes como para investigadores que vincula ambas perspectivas del diseño (la docente e investigadora). Para ello, nos inspiramos en la metodología de investigación Educación Comparada y planteamos un análisis documental de las secuencias, adaptando el protocolo de análisis previamente diseñado en el Estudio 1, categorizando las secuencias de enseñanza y aprendizaje y, finalmente, identificando unos niveles de sofisticación para las categorías que aparecen en el protocolo de análisis.

En el Estudio 3 nos sumergimos en la secuencia de enseñanza y aprendizaje de diseño propio: *Ni flota ni se hunde*. Concretamente, analizamos el efecto que produjo la secuencia en cuestión en la percepción de aprendizaje y emociones de estudiantes del Grado de Maestro en Educación Primaria a través de una lectura desde el marco teórico del clima de aula y flujo. Para ello, analizamos las respuestas que nos han proporcionado 137 estudiantes en formación inicial, implementando una metodología cuantitativa, no experimental, descriptiva, comparativa y correlacional.

Estos tres estudios nos han permitido, por un lado, clarificar cuáles han sido nuestros principios de diseño en la secuencia de enseñanza y aprendizaje *Ni flota ni se hunde* y, por otro lado, rediseñar la secuencia en cuestión para adaptarla al segundo ciclo de Educación Primaria.

Abstract

The Doctoral Thesis *Analysis of teaching-learning sequences on the phenomenon of floating and sinking in the framework of design research* arises as a result of the interest and need of the research groups Sensociencia (UAL) and CRECIM (UAB) to design TLSs based on enquiry and modelling and to reflect on the process that led to their design. In this Doctoral Thesis, following this same line, we intend to clarify the design principles that guided us in the design of our EAS on floating and sinking objects: *Neither floats nor sinks.*

In order to achieve this objective, the Doctoral Thesis has been divided into three studies with their respective research questions. In Study 1, we analyse the contributions that have been made in the educational literature on the phenomenon of floating and sinking. In order to achieve this objective, we carried out a systematic review, selecting 71 research papers with a chronological scope: from the 1970s to the present day. This involved the emergent generation of an analysis protocol and its subsequent application through categorising papers related to the phenomenon of floating and sinking.

In Study 2, we compared five teaching and learning sequences on the phenomenon of floating to identify the most relevant characteristics of each one of them, as well as make the comparison of sequences visible as a resource prior to the design that is relevant for both teachers and researchers, linking both perspectives of the design (the teacher and the researcher). To this end, we are inspired by the Comparative Education research methodology and we propose a document analysis of the sequences, adapting the analysis protocol previously designed in Study 1, categorising the teaching and learning sequences and, finally, identifying levels of sophistication for the categories that appear in the analysis protocol.

In Study 3, we dive into the teaching and learning sequence designed by Sensociencia: *Neither floats nor sinks*. Specifically, we analysed the effect that the sequence in question had on students' perception of learning and emotions of the Degree in Primary Education through a reading from the theoretical framework of classroom climate and flow. To do so, we analysed the responses provided by 137 students in initial training, implementing a quantitative, non-experimental, descriptive, comparative and correlational methodology.

These three studies have allowed us, on the one hand, to clarify our design principles in the teaching and learning sequence *Neither floats nor sinks* and, on the other hand, to redesign the sequence in question to adapt it to the second cycle of Primary Education.

Presentación

La Tesis Doctoral titulada *Análisis de secuencias de enseñanza y aprendizaje sobre el fenómeno de flotación en el marco de la investigación de diseño* ha sido financiada por el Ministerio de Universidades a través de las *Ayudas para la formación de profesorado universitario (FPU)* y por los proyectos SensoDociencia (PID2020-116097RB-I00 financiado por MCIN/ AEI/10.13039/501100011033/ UAL2020-SEJ-D1784) y Prueba a distancia (P_20-00094). Asimismo, cabría mencionar que la Tesis en cuestión ha sido desarrollada en el seno del grupo de investigación *Sensociencia*, en colaboración con el *Centre de Recerca per a l'Educació Científica i Matemática* (Universidad Autónoma de Barcelona), el *Instituto de Educaçao da Universidade de Lisboa* (estancia financiada por la Asociación Universitaria Iberoamericana de Postgrado) y el *Institute for Science Education and Communication* (estancia financiada por el Ministerio de Educación y Formación profesional a través de las Ayudas complementarias de movilidad destinadas a beneficiarios del programa de Formación del Profesorado Universitario).

De acuerdo con la *Normativa de Estudios Oficiales de Doctorado* de la Universidad de Almería (documento aprobado en Consejo de Gobierno en octubre de 2020), estamos ante una *Tesis por manuscrito avalado por publicaciones* (modalidad B), de manera que aportamos un artículo de investigación que acredita la calidad de la Tesis: 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 (Journal of Computing in Higher Education; Journal Citation Reports, Q2).

Atendiendo a los criterios presentados en el documento *Guía de Trámites de Tesis Doctorales* (aprobada por Comisión de Estudios de Postgrado de fecha 15/03/2013, actualizada por la *Normativa de Estudios Oficiales de Doctorado el 29 de octubre de 2020*), el trabajo de investigación que aquí presentamos tendrá la siguiente estructura:

En la *primera sección* de la Tesis planteamos cuál es la motivación que nos ha guiado durante su desarrollo, así como los objetivos y preguntas de investigación; mostramos cuál ha sido el marco teórico que ha permeado todo el trabajo realizado; y, finalmente, el marco metodológico de la presente Tesis Doctoral.

En la *segunda sección* mostramos los tres estudios que forman parte de la Tesis, siguiendo una estructura similar: introducción, marco teórico, preguntas de investigación, metodología, resultados y conclusiones.

Finalmente, en la *tercera sección* recogemos cuáles son las principales conclusiones que hemos obtenido; las implicaciones de la Tesis; las posibles líneas de investigación de cara al futuro; y, finalmente, las referencias bibliográficas.

Así pues, y dado que la Tesis pretende optar a la mención internacional, atendemos a la *Normativa de Estudios Oficiales de Doctorado (29 de octubre de 2020)* y al *Real Decreto 99/2011 (BOE nº35 de 10 de febrero))* presentando en inglés el resumen, los capítulos cuarto y sexto, así como las conclusiones.

Finalmente, fruto del trabajo de la presente Tesis Doctoral, he participado como primer autor en la presentación y divulgación de los siguientes trabajos en forma de artículos y comunicaciones:

- Castillo-Hernández, F. J., Jiménez-Liso, M. R., Martínez-Chico, M., & López-Gay, R. (2020). ¿Cuáles son los ingredientes imprescindibles para indagar en el aula? *Aula de Innovación Educativa*, *298*(Octubre), 26–30.
- Castillo-Hernández, F. J., Jiménez-Liso, M. R., Martínez-Chico, M., & López-Gay, R. (2022). Ni flota ni se hunde: ¿Es posible iniciar el modelo de fuerzas en Educación Primaria? *Aula de Innovación Educativa, 312*(Febrero), 31-35.
- Castillo-Hernández, F. J., Jiménez-Liso, M. R., & Couso, D. (2022). 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. *Journal of Computing in Higher Education*. https://doi.org/10.1007/s12528-022-09312-7

En cuanto a las comunicaciones:

- Castillo-Hernández, F. J., Jiménez-Liso, M. R., Martínez-Chico, M., & López-Gay, R. (2020). Indagación autónoma con la sal como contexto: una experiencia en secundaria. Comunicación oral. *1er Congreso Internacional sobre Educación Científica y Problemas Relevantes para la Ciudadanía*. Málaga, España.
- Castillo-Hernández, F. J., Jiménez-Liso, M. R., Martínez-Chico, M., & López-Gay, R. (2021). La flor en Primaria. Secuencia de enseñanza basada en indagación para la formación inicial docente. Simposio. *XI Congreso Internacional sobre Investigación en la Didáctica de las Ciencias*. Lisboa, Portugal.
- Castillo-Hernández, F. J., Jiménez-Liso, M. R., Martínez-Chico, M., & López-Gay, R. (2021). Equilibrium as trigger of a Model-Based Inquiry sequence on flotation. Simposio. *ESERA 2021: Fostering scientific citizenship in an uncertain world.* Braga, Portugal.
- Castillo-Hernández, F. J., Jiménez-Liso, M. R., Martínez-Chico, M., & López-Gay, R. (2022). An evaluation proposal for pre-service primary teachers: self-regulation of learning and emotions. *95th International Conference of NARST: A global organization for improving science education through research.* Comunicación oral. Vancouver, Canadá.

Asimismo, he participado como coautor en otros artículos, capítulos de libros y comunicaciones: https://scholar.google.es/citations?user=LNZkrmIAAAAJ&hl=es&oi=ao

Índice

SECCIÓN I

1. Introducción y objetivos de investigación

Una de las tareas más recurrentes mientras estudiaba el Grado de Maestro en Educación Primaria fue diseñar secuencias de enseñanza y aprendizaje (SEA a partir de ahora) en casi todas las asignaturas. Recuerdo que, al comenzar el proceso de cada diseño, eran múltiples las preguntas que me venían a la mente: ¿Para qué nivel educativo debería diseñar?, ¿qué quiero enseñar exactamente?, ¿qué enfoque de enseñanza?, ¿qué materiales voy a emplear?, etc. Tratar de dar respuesta a estas preguntas me hizo valorar la dificultad que supone el diseño de SEAs y, más aún, cuando eres un estudiante de grado o un maestro novel y no tienes unas herramientas concretas con las que llevar a cabo dicho proceso.

Para afrontar esta tarea, una de las recomendaciones más habituales por parte de los docentes universitarios era que la SEA partiera de fenómenos cercanos y cotidianos a los alumnos, de forma que el contenido tuviera sentido para ellos (Jiménez-Liso, 2020). Este consejo, que había escuchado en tantas ocasiones durante la carrera, vio su fiel reflejo en la asignatura de Didáctica de las Ciencias Experimentales (DCE a partir de ahora), dado que la profesora María Martínez-Chico, además de plantearlo a nivel teórico, fue coherente con su propia práctica en el aula. Fue la primera vez que un contenido de ciencias, que en este caso era el relativo al modelo Sol-Tierra (Martínez-Chico et al., 2013), tuvo sentido para mí.

Precisamente esta vivencia, y la ilusión por que otros alumnos tuvieran una experiencia similar a la mía, me hizo reflexionar, junto a mis directoras de Tesis, sobre la importancia que tiene incorporar los consensos alcanzados en la investigación didáctica a las SEAs. Sin embargo, trasladar los resultados de investigación al diseño de SEAs es complejo y, de hecho, se asocia a la famosa brecha entre investigación-aula (Zembal-Saul, 2017). De acuerdo con Guisasola & Oliva (2020) este problema tiene larga tradición en el área de DCE, como muestran los iniciales refinamientos de secuencias de actividades o de programas-guías (Gil Pérez & Martínez Torregrosa, 1987) y las más recientes investigaciones basadas en diseño o *desing-based research* (DBR; Easterday et al., 2016; Juuti & Lavonen, 2006; Nieveen et al., 2006), lo que nos estaría indicando la imperiosa necesidad de aclarar el proceso de diseño y operativizarlo en la medida de lo posible.

Enmarcados en el paradigma del DBR, y con el objetivo de superar la conocida brecha entre investigación y práctica docente, la investigación de diseño plantea tres fases: 1) investigación preliminar; 2) desarrollo del artefacto educativo; y 3) evaluación sumativa (Plomp, 2013; Romero-Ariza, 2014). Los artefactos educativos pueden ser las propias SEAs, pero también los principios de diseño, que, en palabras de Plomp (2013), hacen referencia a *experience-based suggestions* (p. 24) que, a modo de brújula, nos guían en el diseño de SEAs (Linn et al., 2004; van den Akker, 1999).

Así, la presente Tesis Doctoral tiene como objetivo clarificar los principios de diseño que nos han guiado en el diseño y posteriores refinamientos de una SEA sobre el fenómeno de flotación y hundimiento de objetos. Cabe mencionar que la SEA en cuestión forma parte del trabajo previamente realizado dentro del grupo de investigación Sensociencia, que tiene como uno de sus ejes principales de investigación el diseño, implementación y evaluación de SEAs fundamentadas en los enfoques de enseñanza de indagación y modelización.

La SEA objeto de investigación de la presente Tesis Doctoral, que recibe el nombre de *Ni flota ni se hunde* (Vokos et al., 2021; pp. 4-5), presenta como fenómeno central la flotación y hundimiento de objetos. La selección de este fenómeno no es casual, sino que, al contrario, lo consideramos muy relevante tanto para el alumnado de Educación Primaria y Secundaria como para la formación inicial de docentes. Se trata de un fenómeno ampliamente conocido y, por tanto, en mayor o menor medida, todos hemos observado algún suceso relacionado con él: un globo que se va hacia arriba, un barco que flota o juguetes en la bañera que flotan o se hunden (argumento de cotidianeidad).

Por otro lado, y quizás por el hecho de ser un fenómeno tan cotidiano para el alumnado, aparece en diferentes currículos del mundo (argumento curricular), ya sea en el contexto hispanohablante (MEFP, 2022) o en el anglosajón (NCE, 2014; NESA, 2017; NGSS, 2013). Además, este interés por el fenómeno de flotación y hundimiento de objetos ha quedado también reflejado en informes internacionales como PISA (OECD, 2012; p. 144), que incluye evaluaciones que lo toman en consideración como contexto.

Desde la DCE también se ha mostrado interés por el fenómeno de flotación, siendo objeto de estudio desde los comienzos de esta área de conocimiento (Rowell & Dawson, 1977b). A pesar del interés temprano por parte de la DCE en cuanto a la flotación (argumento didáctico), continua vigente, como muestran artículos recientes (Espindola et al., 2018; Gao et al., 2020).

Teniendo en cuenta todo lo anteriormente expuesto, y atendiendo al objetivo de investigación que nos marcamos (clarificar nuestros principios de diseño), la Tesis Doctoral está estructurada en tres estudios que responden a los siguientes objetivos de investigación:

En el **Estudio 1** caracterizamos y describimos las contribuciones de la literatura didáctica sobre el fenómeno de flotación y hundimiento de objetos a través de una revisión sistemática. Ello nos permite responder a la siguiente pregunta de investigación:

- ¿Qué consensos arroja la investigación didáctica sobre la enseñanza y el aprendizaje del fenómeno de flotación y hundimiento de objetos? ¿Son transferibles al aula?

En el **Estudio 2** comparamos cinco SEAs sobre el fenómeno de flotación y hundimiento de objetos a fin de extraer las principales características de cada una de ellas y visibilizar la comparativa de SEAs como un proceso propio de la fase previa al diseño, además de las tradicionales revisiones de la literatura. Las preguntas de investigación a responder son:

- ¿Qué características presentan las SEAs disponibles sobre el fenómeno de flotación y hundimiento de objetos?
- ¿Cómo contribuye a la fase preliminar del diseño esta comparación de SEAs fundamentadas en la investigación (Research Based Design)?
- En relación a la toma de datos, ¿podría ser posible un tratamiento sencillo de los datos que permita la comparación de SEAs sobre un tema científico?

En el **Estudio 3** analizamos el efecto de nuestra SEA *Ni flota ni se hunde* en la percepción de aprendizaje y emociones de estudiantes del Grado de Maestro en Educación Primaria. De esta forma, planteamos las siguientes preguntas de investigación:

- ¿Qué percepción de aprendizaje presentan maestros en formación inicial a lo largo de una SEA sobre el fenómeno de flotación y hundimiento de objetos basada en la indagación y modelización?
- ¿Qué emociones perciben haber vivido maestros en formación inicial durante la vivencia de una SEA sobre el fenómeno de flotación y hundimiento de objetos basada en la indagación y modelización?
- ¿Qué información aportan los marcos teóricos del clima emocional y el flujo en relación a la percepción de aprendizaje y emociones de maestros en formación inicial?

Como consecuencia de estos tres estudios y de las conclusiones generales que se derivan de ellos, planteamos una sección final (Implicaciones) en la que mostramos de forma transparente cuáles han sido los principios de diseño que nos han guiado en el desarrollo de la SEA *Ni flota ni se hunde* y el rediseño de esta para adaptarla a Educación Primaria.

A continuación, en la Figure 1, mostramos una panorámica de la presente Tesis Doctoral, indicando los objetivos planteados para los tres estudios, un resumen de las preguntas de investigación descritas en párrafos anteriores y, finalmente, los productos que se van a obtener.

ESTUDIOS	PREGUNTAS DE INVESTIGACIÓN	PRODUCTOS
Estudio 1. Caracterizar y describir las contribuciones de la literatura didáctica sobre el fenómeno de flotación y hundimiento de objetos a través de una revisión sistemática	1. ¿Consensos? ¿Transferibles?	1. Consensos y disensos de la investigación didáctica sobre el fenómeno de flotación y hundimiento de objetos.
Estudio 2. Analizar seis SEAs sobre el fenómeno de flotación a fin de extraer las sus principales características. Visibilizar la comparativa de SEAs como proceso propio de la fase previa al diseño	1. ¿Características de las SEAs? 2. ¿Descripción comparada para la fase preliminar de la DBR? 3. ¿Metodología de la descripción comparada?	1. Las principales características de seis SEAs sobre el fenómeno de flotación y hundimiento de objetos. 2. Ventajas que comporta el uso de la comparativa de SEAs como proceso propio de la fase previa al diseño. 3. Operativización del proceso de comparativa de SEAs.
Estudio 3. Analizar el efecto de nuestra SEA sobre flotación y hundimiento de objetos basada en la indagación y modelización en la percepción de aprendizaje y emociones de estudiantes del Grado en Educación Primaria	1. ¿Percepción de aprendizajes de los futuros docentes al vivir SEA? 2. ¿Emociones percibidas? 3. ¿Clima de aula y flujo?	1. Análisis sobre la percepción de aprendizaje de estudiantes en formación inicial. 2. Análisis sobre las emociones que han experimentado estudiantes en formación inicial. 3. Identificación de los momentos en los que el clima de aula es el adecuado y se produce flujo (concentración y satisfacción).

IMPLICACIONES	
Propuesta de principios de diseño que nos han guiado en el desarrollo de la secuencia de enseñanza y aprendizaje *Ni flota ni se hunde*	Rediseño de la secuencia de enseñanza y aprendizaje *Ni flota ni se hunde* para adaptarla al nivel de Educación Primaria

Figure 1. Esquema que aglutina los objetivos, las preguntas de investigación, los productos de los tres estudios y las implicaciones de la Tesis Doctoral

Como se puede deducir de los párrafos anteriores, desde nuestro grupo de investigación (Sensociencia) hemos querido plantear dos SEAs sobre flotación: una para la formación inicial de maestros (que analizaremos parcialmente en el Estudio 3) y otra para Educación Primaria (que mostraremos en las implicaciones y anexos de esta Tesis Doctoral).

En el comienzo de la introducción, previo a las preguntas de investigación, hemos abordado la motivación que nos ha llevado a elegir el fenómeno de flotación, destacando su presencia en la vida cotidiana, en los currículos educativos y por su abundante investigación en artículos y proyectos. Todos estos argumentos (curricular, cotidiano, didáctico, etc.) fueron suficientes para justificar su incorporación a la formación inicial de maestros. No obstante, no fueron los únicos a valorar, pues también consideramos el argumento epistemológico: aprender sobre la flotación de objetos a través del modelo de fuerzas supone un verdadero choque epistemológico para los futuros docentes, que transitan desde descripciones tales como *flota/se hunde porque es más/menos denso que…* hasta explicaciones en términos de fuerzas. Esto, por tanto, iría en consonancia con las grandes ideas que la enseñanza de las ciencias debe promover (Harlen, 2015).

Otra ventaja epistemológica y procesual a valorar es que, con esta propuesta, los futuros maestros viven en primera persona lo que es un modelo en ciencias: un conjunto de ideas que permiten describir, explicar y predecir fenómenos de la naturaleza, pero también su dimensión instrumental a través de dibujos, maquetas, simulaciones, etc. (Oliva, 2019). De esta manera, al vivir en primera persona una SEA sobre flotación fundamentada en investigación y reflexionar sobre cómo han aprendido y qué han sentido (propuesta que hacemos desde Sensociencia) acortamos la brecha entre ambas pues somos coherentes con nuestra propia práctica docente en la formación inicial.

Además, y dado que la flotación aparece en el currículo español, estaríamos preparando (tanto a nivel didáctico como científico) a los futuros maestros para su enseñanza, ofreciéndoles SEAs, en este caso sobre flotación, basadas en indagación y modelización que les servirán de ejemplo cuando tengan que abordar las diferentes temáticas en sus clases.

En la presente Tesis Doctoral tomamos el proceso de enseñanza y aprendizaje como objeto de investigación a tres niveles (macro, meso y micro), de manera que profundizamos sobre las acciones previas al diseño (revisión sistemática y comparación de cinco SEAs), sobre el propio diseño y sobre la implementación/evaluación del efecto que produce la SEA.

Como futuras líneas de investigación, ampliaremos el análisis micro estudiando las grabaciones de aula durante la implementación de nuestra SEA sobre flotación y continuaremos con la investigación sobre cómo diseñamos. Si queremos enseñar a diseñar a los futuros maestros, primero hemos de tener claro cómo lo hacemos. Una vez clarificado cómo diseñamos, pretendemos conectar la asignatura Didáctica de las Ciencias Experimentales del Grado de Maestro en Educación Primaria con el Practicum y con el Trabajo Fin de Grado, de manera que sea un anticipo de su propio desarrollo profesional docente.

2. Marco teórico

Dada la estructura de esta Tesis Doctoral, cada uno de los estudios presenta una fundamentación teórica concreta y específica. Por ello, en este apartado nos centramos en las prácticas científicas, y, más concretamente, en la indagación centrada en modelos, como el marco teórico que aglutina a toda la Tesis. Esta decisión proviene, en primer lugar, de la importancia que supone el enfoque de enseñanza por indagación para el diseño de SEAs en el grupo Sensociencia, grupo al que pertenezco y en el que se ha generado la presente Tesis Doctoral. En segundo lugar, debido a que uno de los principales criterios para seleccionar las cinco SEAs que forman parte del Estudio 2 de esta Tesis Doctoral ha sido que estuvieran fundamentadas en indagación. Del mismo modo, la SEA analizada en el Estudio 3 (*Neither floats nor sinks*) está fundamentada en dicho enfoque de enseñanza.

Por todo ello, el marco teórico que aquí planteamos considera los siguientes apartados: las dimensiones de la indagación; las principales propuestas que se han realizado desde la literatura didáctica bajo este nombre; las posibles causas de su polisemia; y, finalmente, nuestro posicionamiento en cuanto a qué entendemos, en esta Tesis Doctoral, cuando nos situamos bajo el paraguas del enfoque de enseñanza por indagación.

2.1. Antecedentes del enfoque de enseñanza por indagación

A finales de la década de los 50, coincidiendo con el lanzamiento del Sputnik I, comenzó un periodo de reflexión en Estados Unidos sobre cómo enseñar y aprender ciencias en los colegios e institutos (Barrow, 2006). Esto supuso la publicación de múltiples documentos desde instituciones americanas como *Science for All Americans* (Rutherford & Ahlgren, 1989), *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science, 1993), *National Science Education Standards* (NRC, 1996), *Inquiry and the National Science Education Standards* (NRC, 2000), *Next Generation Science Standards* (NRC, 2013) pero también desde las europeas, destacando el *Informe Rocard* (Rocard et al., 2007) el *Proyecto Pollen* (Worth et al., 2009), *Fibonacci* (Harlen & Léna, 2010) o el *Science Education for Responsible Citizenship* (European Commission, 2015). Dichos informes, que fueron inspirados en la ingente investigación previamente realizada desde el ámbito académico (Alfieri et al., 2011; Lazonder & Harmsen, 2016; Morales et al., 2018; Romero-Ariza, 2017), fueron, en primer lugar, un espaldarazo a la indagación y, en segundo lugar, a las prácticas científicas (Osborne, 2014a) y epistémicas (Kelly, 2008), como medio para enseñar y aprender ciencias.

2.1.1. Dimensiones de la indagación

Este consenso sobre la necesidad de enseñar indagando produjo una moda (Couso, 2014) sin una definición clara, convirtiéndose en un *cajón de sastre* en el que cabían numerosas propuestas de enseñanza muy dispares. De hecho, la definición de indagación puede ser tan amplia como se quiera: Suchman (1968), sin ir más lejos, estableció que la indagación puede ser considerada en sí misma como ciencia. Una definición tan amplia, sin embargo, no es operativa, por lo que se hace necesario acotarla.

En este sentido, Barrow (2006) trató de agrupar todos las definiciones en torno a tres grandes dimensiones:

En la primera de ellas, encontramos a la indagación entendida como un contenido de área cuyo objetivo es que el alumnado comprenda cómo hacen su trabajo los científicos (Jiménez Aleixandre, 2012; Kelly, 2008).

En la segunda, la indagación entendida como las destrezas de los estudiantes para hacer indagación científica. Esto es, las habilidades para hacer e identificar preguntas, planificar y diseñar experimentos, recolectar datos y conectar las pruebas con las explicaciones, etc. (Anderson, 2002; Minner et al., 2010)

En la tercera y última dimensión, la indagación entendida como un enfoque de enseñanza, para la que no hay una propuesta consensuada ni en la comunidad educativa ni en la investigadora (Costas et al., 2018).

Estas tres dimensiones propuestas por Barrow (2006) ponen de manifiesto la dificultad que supone encontrar una definición clara y operativa de indagación. Así, y para aclarar al lector, en la Tesis que aquí presentamos nos ubicamos en la tercera dimensión: la indagación como enfoque de enseñanza. Es por ello que, a continuación, aclaramos qué fases constituyen a la indagación como enfoque de enseñanza según la literatura didáctica.

2.1.2. Fases del enfoque de enseñanza por indagación

Han sido múltiples los intentos de concretar el enfoque de enseñanza por indagación en unos pasos o fases a seguir (Pedaste et al., 2015). Esto, lejos de considerarlo como algo negativo, podría ser un avance pues, por un lado, muestra una mayor transparencia en cuanto qué se entiende por indagación y, por otro lado, facilita el proceso de diseño de SEAs. De hecho, y aunque somos conscientes de que agrupar la actividad científica en torno a unos pasos o fases concretas es algo forzado y artificial y que podría propiciar una visión simplificada de la ciencia, el beneficio es claro: proporciona un marco de referencia muy útil en la presente Tesis Doctoral para, en primer lugar, analizar SEAs elaboradas por otros y, en segundo lugar, diseñarlas. A continuación, por tanto, mostramos algunas de las propuestas más destacadas de la literatura científica.

En el contexto americano, el National Research Council plantea las siguientes fases dentro del enfoque de enseñanza por indagación (NRC, 2000):

- Los estudiantes se enganchan con preguntas científicas, sucesos o fenómenos.
- Los estudiantes exploran ideas incluso en experiencias manipulativas, formulan hipótesis y las ponen a prueba, resuelven problemas y crean explicaciones para lo que observan.
- Los estudiantes analizan e interpretan datos, sintetizan sus ideas, construyen modelos y clarifican conceptos y explicaciones con los profesores y otras fuentes de conocimiento científico.
- Los estudiantes extienden su nueva comprensión y habilidades y aplican lo que ellos han aprendido a través de nuevas situaciones.

En el contexto europeo, el proyecto Pollen (Worth et al., 2009) destaca las siguientes fases: 1) involucrar o comprometer; 2) diseñar y llevar a cabo investigaciones científicas; 3) obtener conclusiones; y 4) comunicar a los demás. Estas fases, además, están sustentadas en seis actividades clave: discutir, cooperar, debatir, intercambiar, reflexionar y registrar.

Asimismo, una de las propuestas más citadas en el panorama internacional es la propuesta de Bybee, que abarca tanto a la indagación (Bybee, 2006) como la enseñanza STEM (Bybee, 2014). La propuesta en cuestión es denominada *5E learning cycle* y está organizada en torno a cinco fases: *engagement, exploration, explanation, elaboration* y *evaluation.*

Estas son tres de las propuestas más reconocidas a nivel internacional. Sin embargo, y dada la cantidad de las mismas, diferentes autores han tratado de reunir y sintetizar lo propuesto desde la literatura científica. The inquiry synthesis project (2006), por ejemplo, destaca cuáles son las características principales de la enseñanza por indagación a partir de una revisión de recursos y literatura. De esta forma, llegan a la conclusión de que la enseñanza por indagación tiene cinco componentes básicos: pregunta, diseño, datos, conclusión y comunicación (p. 4).

Pedaste et al. (2015), por su parte, realizan una revisión sistemática a partir de 32 artículos con el fin de identificar y resumir las características principales de las propuestas de indagación realizadas desde la literatura científica. Los autores de la revisión, tras tres rondas de análisis, identificaron cinco fases junto con algunas sub-fases: orientación, conceptualización (sub-fases: cuestionamiento y generación de hipótesis), investigación (sub-fases: exploración, experimentación e interpretación de datos), conclusión y discusión (sub-fases: reflexión y comunicación).

Así pues, y gracias a la transparencia con la que se ha mostrado en la literatura científica qué se entiende por indagación y cómo implementarlo en el aula, podemos llegar a la conclusión de que, bajo un mismo paraguas, caben infinidad de propuestas: desde una tradicional práctica de laboratorio a un programa de aprendizaje autónomo de los estudiantes (Barrow, 2006). Es por ello que, en el próximo apartado, queremos reflexionar sobre los reduccionismos asociados a este enfoque de enseñanza.

2.1.3. Reflexión sobre los reduccionismos asociados al enfoque de enseñanza por indagación

La indagación, como enfoque de enseñanza, ha sido asociada a multitud de propuestas educativas que, en la mayoría de los casos, la reducen a actividades manipulativas basadas en una imagen *empírica* de la ciencia (Couso, 2014). Para evitar este énfasis en el *cacharreo*, el NRC (2012), así como Osborne (2011, 2014), proponen un cambio de nomenclatura, pasando del término *indagación* a las *prácticas científicas*. Este cambio, sin embargo, no hizo referencia única y exclusivamente a la nomenclatura, sino también a las prácticas asociadas: además de la indagación, ganan relevancia la modelización y la argumentación, poniéndolas al nivel de la primera. En esta misma línea, Garrido & Couso (2017) insisten en que no es suficiente con permitir que se indague con fenómenos, sino que se hace necesaria la ayuda del experto, en el momento adecuado, que enfoque la mirada y aporte ideas nuevas.

Estas críticas son acertadas, pero, desde nuestro punto de vista, no apuntan al corazón de la enseñanza por indagación, sino que advierten de los siguientes reduccionismos:

- Reducir la indagación únicamente a plantear cuestiones abordables por la ciencia (Crujeiras & Jiménez-Aleixandre, 2012).
- Considerar que indagar es solo planificar y poner en práctica investigaciones (Crujeiras Pérez & Jiménez Aleixandre (2015; NGSS, 2013).
- Identificar indagación con recogida de datos (data collection, Wilhelm & Beishuizen, 2003) o búsqueda de información en la web (Zhang & Quintana, 2012).
- Centrar la indagación exclusivamente en el desarrollo de destrezas manipulativas como observar, medir, usar instrumentos, como telescopios o campos magnéticos (Giere, Bickle, & Mauldin, 2006; NRC, 2000; Osborne, 2014).

En los dos primeros reduccionismos subyace la idea de autonomía como elemento de gran relevancia para la indagación, sin tener en cuenta que el exceso de ella solo conlleva dificultades añadidas y una efectividad escasa (Aguilera Morales et al. 2018; Ferrés Gurt 2017; Romero-Ariza 2017) o que en las propuestas de indagación se pueden plantear progresiones que van desde las más cerradas hasta las más abiertas (NRC, 1996). Esta identificación no tiene en cuenta que los docentes pueden diseñar actividades que guíen el proceso enseñanza-aprendizaje incluyendo una pregunta que *enganche,* aportar uno o varios diseños para que sean evaluados en función de su conveniencia, etc., sin que por ello deje de ser una buena práctica de indagación (Jimenez-Liso et al., 2020)

El tercer reduccionismo (identificar indagación con recolección de datos) puede llevar al error de considerar como sinónimos a los datos y las pruebas. Ambos términos tienen funciones diferentes: en el caso de las pruebas, aceptar o rechazar una hipótesis para apoyar una conclusión, mientras que los datos (hechos, fenómenos, informaciones, cantidades, magnitudes, relaciones, testimonios, etc.), per se no conducen a ninguna comprobación ni conclusión. Los datos son necesarios, pero no suficientes, para no dejarnos llevar por las percepciones o por las ideas personales u opiniones (Jiménez-Aleixandre, 2010; pp. 72-74). Asimismo, de este reduccionismo también parece intuirse que la única forma de obtener los datos es mediante su recogida durante la SEA. Sin embargo, y como señala Kelly et al. (1998), los datos (hipotéticos o empíricos) pueden ser suministrados por la propia tarea u obtenidos por el alumnado de su propia experiencia o de una indagación diseñada *ad hoc* (Jiménez-Aleixandre, 2010). En resumen, el tercer reduccionismo puede llevar a una visión de la indagación empirista, aproblemática y ateórica (Fernández et al., 2002).

Esta imagen empirista de la indagación, criticada por numerosos autores (Harlen & Léna, 2010; Worth et al., 2009), e incluso desde la filosofía de la ciencia (Izquierdo-Aymerich & Adúriz-Bravo, 2003), parece estar generando el último reduccionismo citado (indagación como sinónimo del desarrollo de destrezas) al pasar desapercibida la conexión de la indagación con los modelos científicos escolares (Jiménez-Liso et al., 2019). Cuando tratamos de definir las tres prácticas científicas (indagación, modelización y argumentación), la primera de ellas suele asociarse con el mundo real, y, por ende, con la adquisición de destrezas o habilidades como observar, medir, usar instrumentos, etc. (Giere et al., 2006; NRC, 2000; Osborne, 2014b). Sin embargo, es precisamente esta conexión con el mundo real lo que permite construir un tipo de conocimiento (el descriptivo) que será esencial para la construcción de explicaciones (Castillo-Hernández et al., 2020). Sin esta conexión, por tanto, se estaría promoviendo una indagación asociada a actividades o destrezas manipulativas (*hands-on*), en lugar de prácticas científicas como buscar pruebas, analizar, contrastar con las ideas personales, etc. que conectan más con la construcción de conocimiento (minds-on, NRC, 2012; Osborne, 2014a)

2.2. Caracterización del enfoque de enseñanza por indagación basada en modelos del grupo Sensociencia

Como indicábamos en la introducción de este marco teórico, ante las numerosas propuestas que se acogen bajo la denominación de indagación, desde el grupo Sensociencia hemos tratado de caracterizar una propuesta concreta que refleje cuál es nuestra propia interpretación sobre el enfoque de enseñanza por indagación basada en modelos. Desde los primeros acercamientos a este enfoque (Martínez-Chico & López-Gay, 2010), que luego se materializaron en una propuesta de formación inicial de docentes (Martínez-Chico, 2013), hasta la actualidad, hemos ido perfilando una propuesta que, como no podía ser de otra forma, ha sido indudablemente influenciada por la reflexión continua y constante con el grupo CRECIM de la Universidad Autónoma de Barcelona (Couso, 2020; Garrido Espeja, 2016)

2.2.1. Propuesta de Sensociencia para el enfoque de enseñanza por indagación basada en modelos

Las dimensiones previamente descritas de la indagación, así como los reduccionismos y críticas a evitar, nos ayudaron a definir nuestro propio ciclo de indagación. De esta forma, mostramos de forma transparente, por un lado, qué entendemos por indagación como enfoque de enseñanza y las fases que la componen y, por otro lado, cuál es el fundamento de las SEAs que diseñamos, así como las lentes con las que analizamos el resto de SEAs basadas en este mismo enfoque (Figure 2).

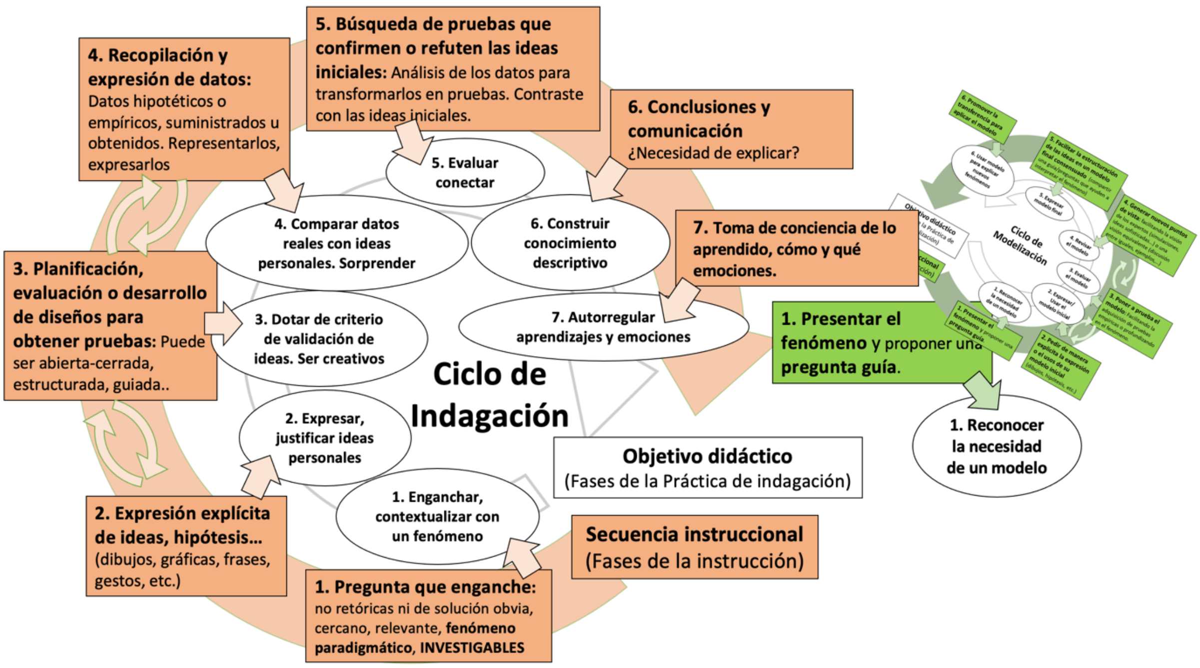


Figure 2. Ciclo de indagación (Jiménez-Liso, 2020; Jiménez-Liso et al., 2019) y modelización (Couso et al., 2020; Couso & Garrido, 2017)

Este ciclo de indagación (Figure 2), que es uno de los resultados de la presente Tesis Doctoral (Jiménez-Liso, 2020; Jiménez-Liso et al., 2019) y que está inspirado en el ciclo de modelización (Couso, 2020; Garrido Espeja, 2016), considera dos aspectos: por un lado, las fases de la secuencia instruccional (cuadros en color naranja) y, por otro lado, los objetivos didácticos vinculados a cada una de esas fases (elipses en color blanco). El ciclo está formado por seis fases diferentes, que desarrollamos a continuación.

En la primera fase planteamos una pregunta que engancha al alumnado y que da sentido a toda la secuencia. Esta pregunta ha de captar la atención de los alumnos y, por tanto, sorprenderlos. Asimismo, la solución a esta pregunta no debe ser obvia, evitando, así, que traten de responder con información previamente memorizada (conocimiento académico) o buscada a través de diversos recursos (como Internet o libros de texto). Para ello, es necesario que la pregunta esté contextualizada, sea relevante para el alumnado, que trate sobre un fenómeno paradigmático y, por último, que sea investigable. No todas las preguntas son igual de válidas para fomentar la expresión de ideas por parte del alumnado (Jiménez-Liso, 2020).

En la siguiente fase de indagación, tras plantear la pregunta que engancha, los alumnos expresan sus ideas personales de forma justificada. Es importante remarcar que ambas, la respuesta y su justificación, han de ser entendidas como sus hipótesis y que estas podrán ser expresadas a través de diferentes lenguajes, como por ejemplo, el verbal, gestual, matemático, etc., en función del nivel educativo en el que nos encontremos. Esta fase de la indagación es de gran relevancia para nosotros pues permite, tanto al alumnado como al profesorado, tomar conciencia sobre qué es lo que piensan sobre un fenómeno. Del mismo modo, esta toma de conciencia sobre sus ideas es de gran relevancia para establecer una progresión de aprendizaje (Castillo-Hernández et al., 2020).

Las siguientes tres fases tienen un eje común: la búsqueda de pruebas y la evaluación de su validez y utilidad. Para ello, en primer lugar, planificamos un diseño (sea experimental o no) que nos permita obtener datos. Esto puede ser realizado de múltiples maneras en función del grado de apertura de la indagación: desde las más guiadas (donde los docentes proporcionan el diseño) hasta las más autónomas (donde los alumnos son los encargados de plantear el diseño), pasando por opciones intermedias (donde los docentes aportan diversos diseños y el alumnado los evalúa) (Castillo-Hernández et al., 2020). Así pues, e independientemente de que sea más o menos guiado el proceso, la evaluación que se haga sobre la validez del diseño es esencial, dado que se trata del criterio que utilizamos para aceptar o rechazar ideas. En segundo lugar, los alumnos recopilan los datos, pudiendo recogerse in situ o, por el contrario, obtenerlos a partir de otras investigaciones (datos secundarios), ser proporcionados por los docentes mediante páginas web fiables o ser buscados por ellos mismos, etc. Lo más relevante de esta fase supone la recogida de datos, ya sea de forma experimental o a través de fuentes secundarias, rompiendo, de esta forma, con la identificación de la indagación con *cacharreo* o actividades manipulativas. En tercer lugar, y como decíamos anteriormente, los datos por sí solos no pueden ser considerados como pruebas, pues no permiten al alumnado aceptar o refutar sus concepciones. Por ello, es necesario que nos detengamos a analizar los datos para estudiar cuáles nos sirven como pruebas y cuáles no, conectándolos con la pregunta inicial y sus respuestas a ella (Jiménez-Liso et al., 2019).

Posteriormente, proponemos al alumnado una actividad de síntesis en la que reflexionamos sobre qué ideas relacionadas con el fenómeno inicial han sido confirmadas y en qué nos basamos para ello. Las conclusiones obtenidas tras el ciclo de indagación suelen llevarnos a la construcción de conocimiento descriptivo. Pensamos que este tipo de conocimiento, a veces infravalorado en la enseñanza, debe jugar un papel importante en el conocimiento científico por su cercanía a lo experiencial y porque constituye un punto de partida sólido que genera la necesidad de la construcción de explicaciones. Sin este conocimiento próximo a la observación y la experiencia no se pondrán en duda los pre-modelos, *modelos de datos* (Koponen, 2007) o *modelos locales* (Armario et al., 2019), iniciando así el ciclo de modelización. En otras palabras, el conocimiento descriptivo construido como consecuencia del ciclo de indagación es el que genera la necesidad de buscar un conocimiento explicativo-interpretativo, producto del ciclo de modelización (Couso et al., 2020; Couso & Garrido, 2017).

Dado que consideramos que la educación no es solamente un proceso cognitivo, sino también afectivo (Bellocchi et al., 2014; Pekrun & Linnenbrink-Garcia, 2014), proponemos a nuestros alumnos que reflexionen sobre qué han percibido aprender, cómo lo han hecho y qué emociones han vivido durante el transcurso de la SEA. Este momento de reflexión es de gran relevancia para nosotros pues favorece que el alumnado tome conciencia de los aprendizajes adquiridos durante la SEA, pero también de que hacer ciencia emociona (Jimenez-Liso et al., 2021; Jiménez-Liso, 2020).

2.2.2. Elementos indispensables para identificar a una SEA como indagación

De todas las etapas que indicamos en el ciclo de indagación anterior (Figure 2), es necesario responder a la pregunta: ¿qué elementos nos parecen indispensables para considerar que una SEA sigue un enfoque de enseñanza por indagación?

Después de muchas opciones, consideramos que son dos las fases imprescindibles para calificar a una SEA bajo el término de indagación: 1) Expresión y discusión de ideas personales y 2) Búsqueda de pruebas.

2.2.2.1. Expresión y discusión de ideas

Los estudiantes se enfrentan con preguntas y problemas relacionados con fenómenos del mundo natural o tecnológico que favorecen la expresión y discusión de ideas personales. Cuando los alumnos se ven obligados a comunicar y defender sus ideas, a argumentar, se produce una toma de conciencia de sus propias explicaciones del mundo y un primer momento de autorregulación sobre esas ideas. El mejor procedimiento para ello consiste en plantear preguntas en contexto que guíen todo el proceso de indagación y, de esta forma, tenga sentido para ellos. Como hemos dicho anteriormente, esta pregunta no puede ser obvia ni retórica sino que debe enganchar (conectar) con las ideas personales y movilizarlas.

Así, y dado que el planteamiento de preguntas en contexto es de gran relevancia, parece lógico que la DCE haya puesto grandes esfuerzos en vincular la ciencia escolar con los aspectos cotidianos de la vida (Jiménez-Liso & De Manuel Torres, 2009). En este sentido, nos parece apropiada la definición planteada por Jiménez-Aleixandre (2010) en cuanto a contextos relevantes y auténticos, la cual hace referencia a aquellos en los que hay un verdadero problema a resolver, cuya respuesta no aparece en un libro de texto, que tengan un cierto grado de apertura, que no sean una única respuesta y, por último, que fomenten la participación del alumnado en las prácticas científicas de formulación de hipótesis, de contraste de pruebas, de argumentación, etc.

2.2.2.2. Búsqueda de pruebas

Fruto de esa discusión inicial, aparecen distintas respuestas, en relación a la pregunta, que no son coincidentes. El criterio para decidir qué respuestas son correctas y qué modificaciones son necesarias realizar en las explicaciones personales no es la autoridad sino las pruebas. Por ello, un elemento característico de la enseñanza por indagación es la búsqueda de pruebas a partir de datos, lo que incluye diferentes acciones: diseñar experiencias, obtener datos, analizar los datos para transformarlos en pruebas, obtener conclusiones y comunicarlas (aunque no todas estas acciones tienen que estar presentes necesariamente en la secuencia de indagación).

Podemos decir que, cuando los estudiantes realizan estas dos actividades – expresar y discutir ideas (emitir hipótesis) y obtener pruebas para confirmar o rechazar esas ideas –, están realizando una práctica científica de indagación. Si, además, las hipótesis y conclusiones permiten expresar, utilizar y/o evaluar un modelo científico, decimos que esa práctica de indagación va acompañada de una práctica de modelización. Hablamos entonces de enseñanza basada en la indagación y modelización.

2.2.3. Aplicación del marco teórico al desarrollo de la Tesis Doctoral

El marco de referencia aquí planteado, que está formado por el ciclo de indagación (Figure 2) y las fases que lo componen, ha sido de gran utilidad tanto para esta Tesis Doctoral como para las publicaciones y comunicaciones que hemos presentado durante estos últimos cuatro años.

Los comienzos de las Tesis Doctorales suelen ser difusos y, conforme nos adentramos y vamos desbrozando el camino, acabamos concentrando y definiendo la problemática a investigar. Así, al principio de la presente Tesis Doctoral necesitamos aclarar y caracterizar lo que Sensociencia consideraba o no como ciclo de indagación y las fases que lo componían, para, de esta forma, poder usarlo como herramienta de análisis de propuestas de enseñanza basadas en indagación propias y ajenas. La caracterización y definición de la indagación nos sirvió para analizar, en primer lugar, una SEA propia (*¿Un garbanzo es un ser vivo?*) en contexto online-onsite (Castillo-Hernández, Jiménez-Liso, & Couso, 2022; Annex I)

Posteriormente, ya inmersos en las SEAs sobre el fenómeno de flotación y hundimiento de objetos, el marco de referencia ha sido utilizado para seleccionar y describir comparativamente las cinco SEAs que aparecen en el Estudio 2, así como para el diseño y análisis de la SEA del Estudio 3 *Ni flota ni se hunde*. En ambos casos, ha sido clave para analizar los diseños (Castillo-Hernández et al., 2020; Castillo-Hernández et al., 2021, 2022; Castillo-Hernández et al., 2021) y para la evaluación de las fases de la indagación presentes en diferentes SEAs (Castillo-Hernández, Jiménez-Liso, & Couso, 2022; Castillo-Hernández, Jiménez-Liso, Martínez-Chico, et al., 2022a).

3. Marco metodológico

La estructura que hemos dado a la Tesis Doctoral nos ha llevado a desarrollar y describir en profundidad la metodología en cada uno de los estudios. No obstante, el marco metodológico de la investigación de diseño o DBR (por sus siglas en inglés) es común a todos ellos.

Para comprender el vínculo que hemos establecido entre el marco DBR y la estructura organizativa de la Tesis Doctoral, es necesario clarificar cuáles son las fases a la hora de desarrollar una investigación bajo este paradigma. No obstante, para ello es imprescindible aclarar previamente que, dentro del DBR, se plantea la existencia de dos tipos de estudios: 1) *development studies,* cuyo objetivo es desarrollar intervenciones basadas en la investigación como solución a problemas complejos y determinar principios de diseño y 2) *validation studies,* cuyo objetivo es diseñar *learning environments* con el propósito de validar teorías sobre aprendizaje, entornos de aprendizaje o principios de diseño (Plomp, 2013; p. 24). Esta distinción es importante a nivel conceptual, pero también porque, en función del tipo de estudio que se plantee, se realizan unas fases u otras.

En el caso que aquí nos ocupa, y dado que el objetivo final de la presente Tesis Doctoral es plantear una propuesta en la que clarificamos cuáles han sido nuestros principios de diseño para desarrollar la SEA sobre flotación y hundimiento de objetos, nos ubicamos en el primero de los tipos: *development studies.* Así pues, han sido múltiples los intentos de concretar en una serie de fases la metodología DBR (Design-Based Research Collective, 2003; Guisasola et al., 2021; Nieveen & Folmer, 2013). Por su utilidad para la Tesis Doctoral, hemos asumido la propuesta planteada por Plomp (2013):

- Investigación preliminar: esta fase es necesaria para conocer cuál es el problema educativo al que nos vamos a enfrentar. Para ello, se suelen proponer dos tareas: por un lado, conocer el contexto en el que vamos a implementar el artefacto educativo (por ejemplo, una SEA) y, por otro lado, especificar las características que va a tener el artefacto en cuestión (principios de diseño). En esta última tarea es en la que se desarrollan las revisiones de la literatura científica a fin de conocer el estado del arte.
- Desarrollo del artefacto educativo: es la fase en la que se diseña la SEA y/o los principios de diseño en forma de prototipo y se realizan los sucesivos refinamientos hasta alcanzar la versión final. Es en este momento en el que se hace esencial la evaluación formativa, entendiendo a esta como la actividad sistemática que se realiza con el objetivo de mejorar la SEA y los principios de diseño que le acompañan (Nieveen & Folmer, 2013; p. 158). En esta fase, por tanto, se desarrollan múltiples

prototipos, ya sean principios de diseño y/o SEAs, que son evaluados y revisados de forma iterativa.

- Evaluación sumativa: una vez que el artefacto educativo (SEA y/o principios de diseño) tiene el suficiente potencial, se pasa a evaluar su eficacia. Este proceso recibe el nombre de evaluación sumativa y la planificación de su uso va a depender del impacto del artefacto. Si hablamos de un nuevo currículo escolar a nivel nacional sería adecuado el uso de dicha evaluación. En cambio, si el impacto del artefacto se reduce a un nivel más local (una SEA), no es necesario el empleo de la evaluación sumativa, entre otras cosas, porque suele asociarse a procesos muy costosos como encuestas a gran escala. En estos casos más locales, se seguirá usando la evaluación formativa, cuyo objetivo es la mejora del artefacto educativo (Nieveen & Folmer, 2013).

Una vez clarifiacadas cuáles son las fases propias de la metodología DBR, cabría mencionar que no han de ser vistas como categorías cronológicas, fijas e inamovibles, sino como una guía que nos acompaña en el desarrollo del artefacto educativo. Un ejemplo claro de ello es nuestra propia SEA sobre flotación (*Ni flota ni se hunde*), la cual se diseñó en el grupo de investigación Sensociencia (Martínez-Chico & López-Gay, 2010) mucho antes del inicio de esta Tesis Doctoral.

El recorrido de la SEA *Ni flota ni se hunde* es un fiel reflejo de la evolución que ha sufrido el propio grupo de investigación Sensociencia. En una primera etapa, que se caracterizó por el uso de la metodología Research based design o RBD (Leinonen et al., 2008; Mislevy et al., 2017; Quesnel et al., 2018), intentamos trasladar los consensos existentes en la literatura didáctica (uso de principios de diseño de forma implícita) para el diseño de diferentes SEAs (Elvira-Ramírez et al., 2020; María Rut Jiménez-Liso et al., 2020; López-Gay et al., 2009, 2015, 2018), siendo una de ellas la relativa a flotación (Martínez-Chico & López-Gay, 2010). No obstante, a medida que se fueron realizando diseños, comenzamos a percartanos de ciertos patrones. Este hecho, junto con el deseo de enseñar a los futuros maestros a diseñar, nos llevó a reflexionar sobre cómo diseñamos o, dicho con otras palabras, cuál es el proceso que implementamos para desarrollar SEAs. El fin sería, por tanto, hacer explícitos esos principios de diseño que ya veníamos usando de forma implícita para que pudieran ser compartidos con otros docentes e investigadores. El momento en el que nuestro objetivo pasó de *diseñar* a *enseñar a diseñar* supuso, por un lado, el comienzo de la segunda etapa dentro del grupo de investigación y, por otro lado, el cambio hacia un enfoque metodológico DBR.

Así, la SEA *Ni flota ni se hunde* tuvo su punto de partida en el año 2010, cuando, bajo el paraguas RBD, Martínez-Chico & López-Gay (2010) mostraron el diseño de la misma en los XXIV

Encuentros de Didáctica de las Ciencias Experimentales. A partir de ese año (2010) la SEA en cuestión fue implementada en formación inicial de docentes, realizando cambios y rediseñándola en función de los resultados que se obtuvieron cada uno de los años en los que se implementó. Llegamos, así, a la SEA del año 2017/2018, versión que analizamos en la presente Tesis Doctoral (Estudio 3). Llegados a este punto, comenzaría la segunda etapa del grupo Sensociencia, pasando a analizar y determinar cuáles han sido los principios de diseño que nos han llevado al desarrollo de la SEA *Ni flota ni se hunde*. Para ello, seguimos los pasos propios de la DBR, que, como dijimos anteriormente, han marcado la estructura de la Tesis.

Así, en primer lugar, hemos realizado la *investigación preliminar* propia del DBR mediante una revisión sistemática de 71 artículos sobre el fenómeno de flotación y hundimiento de objetos (Estudio 1). En segundo lugar, hemos intentado repensar la etapa de *investigación preliminar* con la incorporación de una nueva tarea a las ya tradicionales (conocer el contexto y revisar el estado del arte): la comparativa de SEAs (Estudio 2). Para realizar la comparativa en cuestión nos hemos inspirado en la tradición de Educación Comparada y utilizado la metodología de análisis documental. Por último, y dado que la SEA ya había sido previamente diseñada, hemos pasado a la evaluación formativa, que forma parte de la segunda etapa del DBR (*desarrollo del artefacto educativo*). En este estudio de evaluación nos hemos centrado tanto en los aspectos cognitivos como afectivos del aprendizaje, analizando la percepción de estudiantes en formación inicial de su aprendizaje y las emociones que han vivido a lo largo de la SEA a través de dos marcos teóricos: clima emocional y flujo (Estudio 3). Cabe mencionar que cada uno de los estudios desarrolla con mayor profundidad las metodologías que se han implementado. En la Table 1 mostramos una panorámica global del proceso metodológico realizado en torno a la SEA *Ni flota ni se hunde*.

Table 1. Fases metodológicas de la SEA Ni flota ni se hunde

<table>
<tr><th></th><th colspan="3">Acción</th><th>Metodología</th></tr>
<tr><td rowspan="2">Etapa 1 (del 2010 al 2016)</td><td colspan="3">Diseño de la SEA Ni flota ni se hunde</td><td rowspan="2">Research based design o RBD</td></tr>
<tr><td colspan="3">Implementaciones sucesivas y refinamiento</td></tr>
<tr><td rowspan="4">Etapa 2 (del 2017 a la actualidad)</td><td rowspan="4">Fases del DBR</td><td rowspan="2">Análisis preliminar</td><td>Estudio de la literatura sobre el fenómeno de flotación y hundimiento de objetos (Fase DBR: análisis preliminar)</td><td>Revisión sistemática</td></tr>
<tr><td>Descripción comparada de cinco SEAs sobre el fenómeno de flotación y hundimiento de objetos</td><td>Educación comparada y análsis documental</td></tr>
<tr><td rowspan="2">Desarrollo del artefacto educativo</td><td>Evaluación formativa de la SEA Ni flota ni se hunde: percepción de aprendizaje y emociones mediante el marco teórico del clima emocional y el flujo</td><td>Estudio cuantitativo: no experimental, descriptivo, comparativo y correlacional</td></tr>
<tr><td>Otros estudios aún no realizados (ver apartado Líneas de investigación futuras)</td><td>Estudios cualitativos</td></tr>
</table>

SECCIÓN II

4. Estudio 1. A Systematic Review about floating and sinking in the Search for Consensus

4.1. Introduction

From the first experiences of having a bath or playing in the pool, the phenomena of floating and sinking are part of our daily life, so trying to explain them from an early age is, according to scientific literature, very common (Paños et al., 2022). Perhaps for this reason the topic had been historically present in official curricula and is taught in schools from the earliest educational stages. However, an informal survey of people around us will show us very few adults and young people are able to explain how an ocean liner of more than 200,000 tons can actually float or why a piece of some woods float while others sink. It could then be said that a lifetime of schooling has not guaranteed reasonable knowledge on a subject (floating and sinking) that, in theory, has been taught and learned previously in compulsory education.

In Science Education (SE), many authors have researched different aspects of the teaching and learning of flotation (Gao et al., 2020; Havu-Nuutinen, 2005; Rowell & Dawson, 1977a), including ideas or Teaching Learning Sequences (TLS in advance, Brinks & Brinks, 1994; Sanger et al., 2009; van Riesen et al., 2018). This is one of the most researched topics with papers published more than 40 years ago. However, this does not mean that how to teach the topic of floating and sinking is completely clear, and this could highlight not only a gap between research and practice but also a gap between research and research, maybe a lack of consensus inside the SE research. Searching if the research yields the necessary consensus for teachers to be able to underpin their teaching in this topic, we have raised the following questions the following questions: Will these well-intended teachers be able to find the main misconceptions of the students to anticipate those of their own students? Will they find the big ideas that explain the ocean liner or the iceberg-sea level problem in the literature? Will they be able to find appropriate contexts to work with according to the age of their students? Or TLSs useful and transferable to their students?

In order to know what actually happens in SE research on the phenomena of floating and sinking, in this paper we offer a systematic literature review, this being a research methodology in which previously published papers on specific topics are selected following a series of criteria and protocols (e.g., inclusion and exclusion criteria or the decision of which approach to follow to reduce bias), reviewed, analysed and synthesized to obtain conclusions that favour the formulation of concrete recommendations (Cohen et al., 2018).

This systematic literature review is of high interest for SE research because through it we look at the historical development of the SE field from a topic that has been present in its publications since the 1970s. It is not usual to take a look at the SE area from the historical evolution of the knowledge of the pedagogical content of a specific topic, since, generally, authors focusing their attention on *research trends* through what has been published over the decades (Lee et al., 2009; Lin et al., 2014; Lin et al., 2019; Tsai & Wen, 2005) or on the characterisation of the different stages in the field (Ariza, 2018; Fensham, 2004; Izquierdo-Aymerich & Adúriz-Bravo, 2002). Analysing historical pedagogical content knowledge about floating and sinking will be to look at itself in the mirror of SE's own history and reflect its achievements and challenges interest both SE researchers and Science Teachers.

4.1.1. Background

Many of the systematic literature reviews on topics that appear in the science curriculum have on the whole focused on describing the alternative conceptions of students. Particularly noteworthy amongst these recent studies, for example, is the bank of conceptions by Pfundt and Duit (1991, updated in 2009), the review by Andersson (1990) on matter and its transformations, that by Garnett et al. (1995), centred on other topics relating to chemistry and the one by Wood-Robinson (1991, 1994) on biology related topics (*inheritance/evolution and plants*). Likewise, we also find current reviews such as those by Hull et al. (2021) on *naïve ideas from a range of topics in physics*.

All of these systemic reviews have summarised or grouped, independently of the methodology used, the main alternative conceptions of students in relation to the different disciplines of science, such as for example biology, physics or chemistry. Notwithstanding this, and despite the fact that some of them do present recommendations for enhancing student learning (Garnett et al., 1995), it is clear that there is a niche of research concerned with seeking consensuses for studies on teaching proposals in order to make improvements in the teaching of the learning difficulties recognised.

Putting the emphasis on the analysis of the teaching proposals regarding floating and sinking and on the possible consensus/dissensus regarding these proposals, we will recover the technoscientific dimension of SE and connect it to research design, which have the objective of improving science teaching via the creation of SE-specific products or technologies, with these summarised into sequences of activities, educational programmes, etc. To do so, we raise the level of the systematic literature reviews of some antecedents focused exclusively on the review of the alternative conceptions, towards the search for consensuses in relation to the teaching proposals described and evaluate their effectiveness in teaching literature.

4.2. Goals and research questions

In this research, we propose a systematic literature review to analyse the development of the SE research on floating and sinking through the study of the publications on the field. We include an analysis of the research objectives of these papers, the concepts used to explain floating and sinking, the testing objects and the teaching approaches they refer to at both Primary and Secondary educational levels.

The interest is twofold: on the one hand, there is an intrinsic interest in this systematic literature review for those interested in further research and teaching and learning on floating and sinking. On the other hand, the analysis of a historically-interesting topic such as floating and sinking offers us an excellent opportunity to study the historical development of a SE topic and characterise the consensuses (and dissensions) reached as a consequence of its appearance and continued interest therein throughout all these years of investigation.

Taking into account this double aim, the research questions we have posed in the present investigation are the following:

- What are the research objectives of papers on floating and sinking and how does these objectives evolve along time?
- What alternative conceptions do students present regarding the phenomena of floating and sinking?
- What are the characteristics (concepts, testing objects, teaching approaches, tested TLS) of the teaching proposals on the topic of floating and sinking?

4.3. Methods

With the aim of helping other researchers in being able to transfer this way of undertaking reviews to other topics and being as transparent as possible with the procedure, we show the process carried out for the selection of the analysed SE papers, and the process followed for their analysis.

4.3.1. Search procedure and selection of papers

Our first step involved searching for the databases in order to fulfil our objectives. In this regard, and for reasons of feasibility, we consider two databases: Web of Science or *WoS* (provided by Thomson Reuters) and Education Resources Information Center or *ERIC* (sponsored by the Institute of Education Sciences of the U.S. Department of Education). They are the most interesting options, given that in the case of the former, it is a tool that draws together different databases relating to the Sciences and Social Sciences, and the fact that the latter is characterised for being the biggest specialised database in the field of education.

To do the systematic literature review, we have followed a similar path to the one presented by Moher et al. (2009) (Figure 3). The paper in question shows a tool called PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses), which was developed after a meeting with 29 specialists. The objective of this meeting was to summarize a series of recommendations and present the necessary steps to carry out a systematic literature review so that the quality of these would improve and possible biases would be avoided. Thus, and with the aim of developing the most appropriate systemic review possible, we consider it necessary to follow these recommendations, as well as the phases they proposed.

Taking this into account, in September 2020 we carried out the first search, defining the different keywords we would use. The number of papers obtained following the database search must be manageable, to which the second step we undertook was a joint meeting with the authors of the papers to establish what keywords would be the most appropriate. Thus, and following the debate that arose from the meeting, we proposed the following keywords: '(flotation OR buoyancy OR sinking OR floating) and education'. The inclusion criteria were as follows:

- It was necessary for the documents to originate from scientific journals and, therefore, to be papers.
- It was necessary for the papers to be peer evaluated.
- We included papers from all possible decades (without restrictions on dates).
- The selected language was English.
- We accepted papers from all educational levels.
- The topic of floating and sinking had to be addressed from the scientific perspective, that is, papers in which density and/or forces appear as main concepts.

Appling all of these inclusion criteria and eliminating all those that were duplicated in both databases, we obtained a total of 283 papers (Identification phase; Figure 3). With the objective of eliminating papers outside our subject matter, we first proceeded to read the title, and then the abstract of the papers (Screening phase; Figure 3). A number of papers that were eliminated made reference, for example, to topics such as 'population density'. In this manner, the sample was reduced to 155 papers. Following on, we carried out a complete reading of the papers and eliminated those in which the inclusion of density or forces was anecdotal, given that they focused on many other general science contents (Eligibility and Included phase; Figure 3). After this final selection step, the final sample consisted of 71 papers.

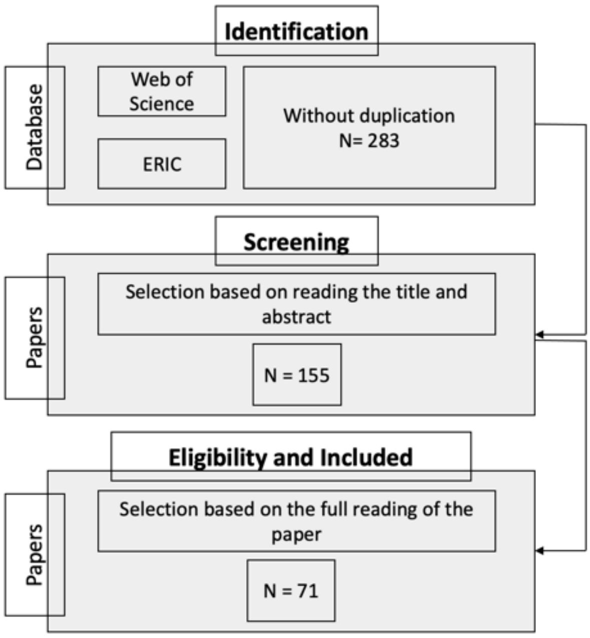


Figure 3. Search procedure based on PRISMA (Moher et al., 2009)

4.3.2. Paper analysis

The initial point of our analysis comprised the design of an analysis protocol to characterise both analysed dimensions of the research papers: students' ideas and teaching proposal. For this to occur, we first defined the elements to include in the analysis protocol: 1) the research aims proposed by the papers; 2) the concepts related to floating and sinking; 3) the testing objects used; 4) the teaching approach they set out; 5) the evaluation of the proposals; and 6) the educational level on which the papers focus.

After highlighting the aforementioned aspects, two researchers independently read a reduced sample of papers (20) in order to obtain the categories that would emerge to form part of the analysis protocol. When category saturation was reached, the three authors independently evaluated the analysis protocol by applying it to five papers and agreeing on a definition for each category. From this point we met on numerous occasions to debate and discuss the categories included in the protocol and establish any necessary changes. For example, at the beginning, we considered that the papers had three different objectives: to diagnose students' ideas, to promote the change of these ideas and, finally, to design activities or TLS. Thus, after multiple meetings, we decided that it would be more appropriate to group the last two under the title of 'teaching proposals' since all the papers that wanted to promote the change of ideas in the students did so by means of 'teaching proposals'. This process was carried out on multiple occasions during the analysis, in a way that the protocol underwent repeated evaluation. It is important to notice that, for the categorisation of the papers, we have opted for the explicit exposition in the body of said papers. Two aspects should be taken into account in relation to the teaching approaches: on the one hand, and despite the fact that some of them could be considered to belong to the 'same or similar family', we have given priority to keeping the name provided by the authors and, on the other hand, there are certain papers in which the teaching approach was not made explicit, but given its clear structure we were able to associate it to a specific category. For a comprehensive view of the analysis protocol, refer to Annex II.

After obtaining a definitive version of the analysis protocol, the authors independently coded the papers, understanding for codes as an abbreviated version of the categories of the analysis protocol. For example, we used the code ID if an article was coded as 'ideas diagnosis'. Thus, to carry out the coding, we employed the ATLAS.TI (version 9) software program. After finalising the process, the authors met to establish the consensuses (and dissensions) regarding the categorisation. In this case, we reached an agreement percentage of over 90%. The dissensions were overcome through debate and discussion. To assure ourselves of the temporal validity of the analysis protocol, the coding of a sample of papers was implemented again one month afterwards and, confirming total coincidence, we approved the consistency.

Taking all of this into account, we then show a tree diagram in which we display the structure we follow in the next section (from left to right), along with the questions that have been our guide for selecting and analysing the research papers (Figure 4).

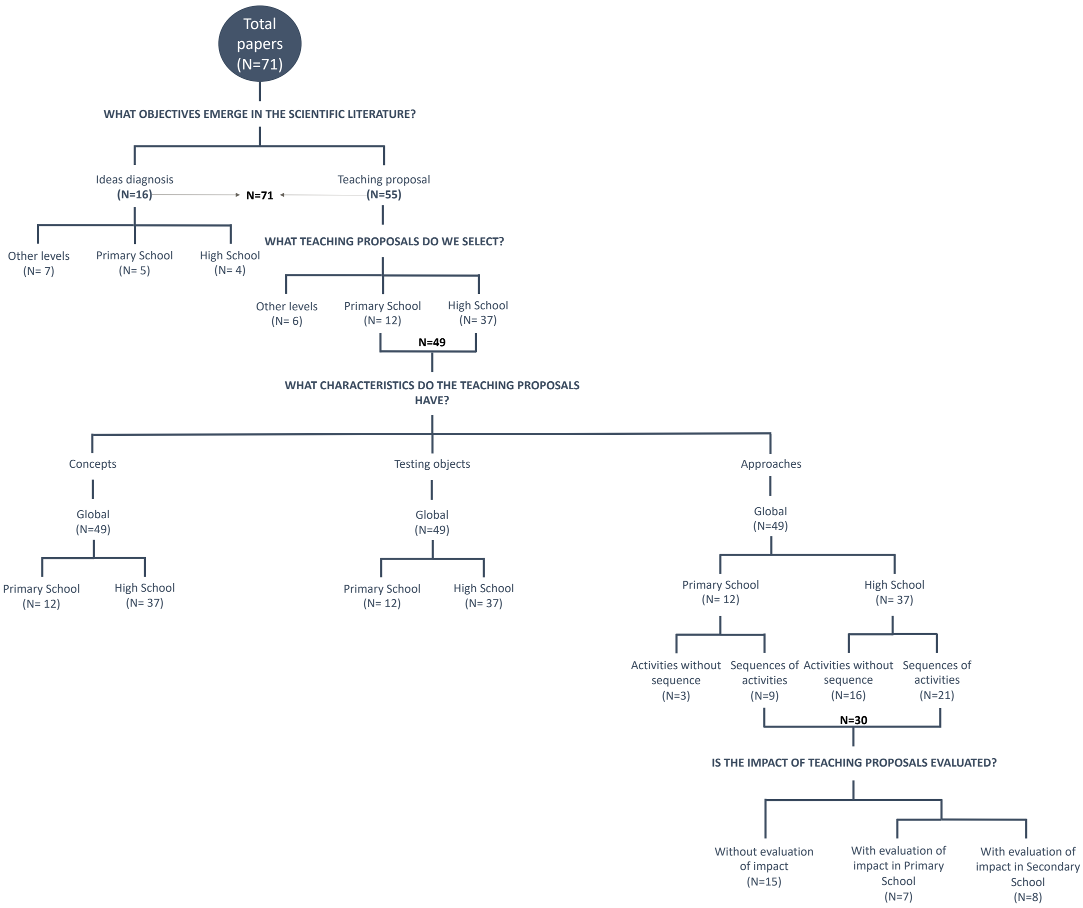


Figure 4. Research questions and structure of the analysis

4.4. Results

In this section we present the main findings of the systematic literature review of papers relating to the phenomena of floating and sinking. The structure will be as follows: firstly, we show the historical evolution of the research objectives relating to floating and sinking, along with their distribution by educational levels; secondly, we indicate what the most relevant alternative conceptions are on the phenomena of floating and sinking; and, finally, we present the most characteristic aspects of the teaching proposals that appear in the scientific literature.

As for the first subsection, we describe the main research objectives presented in SE papers regarding the phenomena of floating and sinking and then analyze how these objectives are distributed by educational level and how they evolve along time. To do this, we first employ the total sample (N=71; Figure 5), but also the Primary and the Secondary levels (N=58; Figure 6).

4.4.1. What are the research objectives of papers on floating and sinking and how does these objectives evolve along time?

In our systematic literature review we have found that papers on floating and sinking put forward two large aims: on the one hand, the so-called *ideas diagnosis*, which refers to those papers aimed at obtaining the alternative conceptions and/or difficulties of students and, on the other hand, the *teaching proposal*, which refers to those papers that have the fundamental purpose of changing said alternative conceptions via didactic propositions (for further information, consult Annex II). Some examples representative of such objectives would be the one presented by Kohn (1993, p. 1641), who argues that *the purpose of the present studies was to explore preschoolers' early understanding of density (as manifested in buoyancy in water) with a simple task* (ideas diagnosis) and that of Leuchter et al. (2014, p. 3), who specifies that *In the current research project, we therefore investigated the effects of a curriculum on the topic of 'floating and sinking' on young children's conceptual knowledge as one way of implementing a structured inquiry-based curriculum that includes scaffolding elements in the early years of schooling* (teaching proposal).

We have considered the distribution of the papers in terms of their objectives by educational level (N=71; Figure 5) and another by decades (N=58; Figure 6). In the first one (Figure 5), we consider the following educational levels: Early Childhood Education, Primary, Secondary, College, Pre-Service and In-Service. In all of them, 'ideas diagnosis' will be represented with green and 'teaching proposals' with red. In the second one, we took into account exclusively Primary Education (N=16) and Secondary Education levels (N=42), obtaining a total sample of N=58. In order to represent Primary and Secondary Education we used the same range of colours (green and red), but in Primary Education the colours will be represented with lighter tones than in Secondary Education.

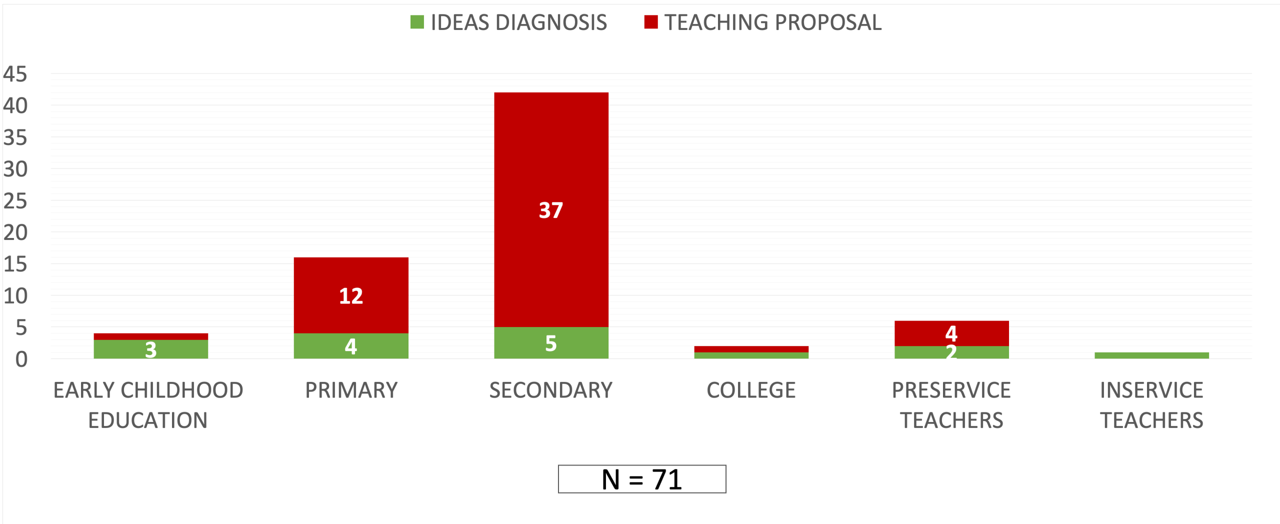


Figure 5. Goals for level (global analysis)

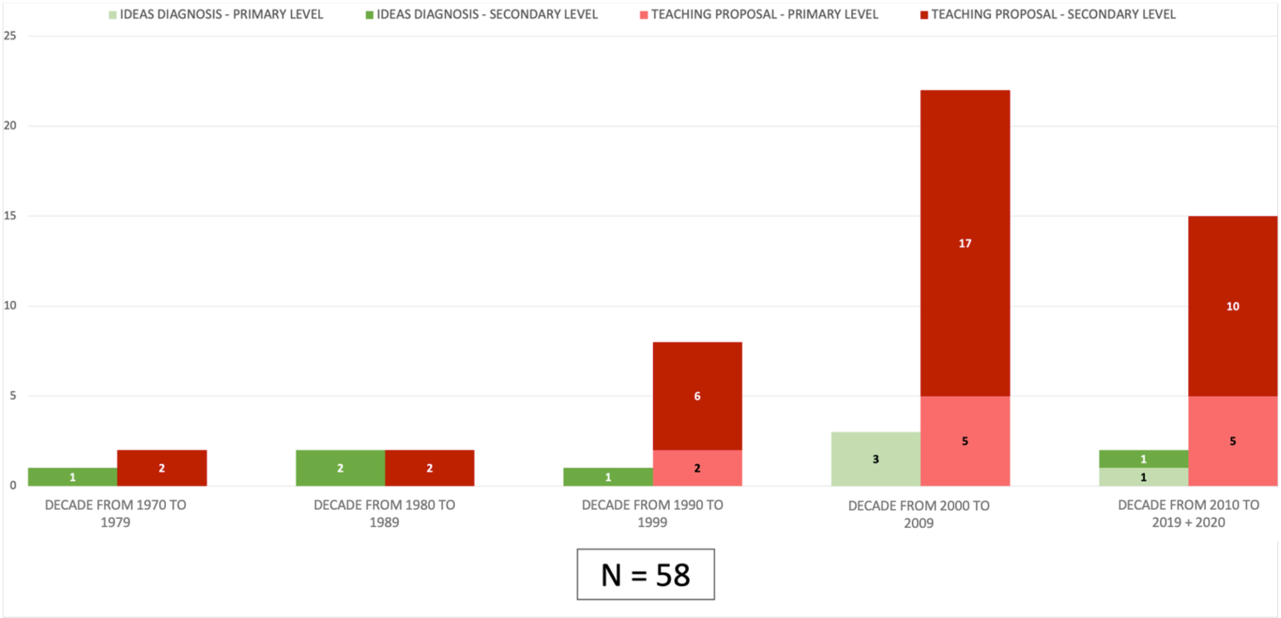


Figure 6. Goals for decade in Primary and Secondary Education

A first comment on Figure 5 suggests that the greatest concentration of papers is found in Primary and Secondary Education, with the rest of the papers from other educational levels being a minority. This fact is what has brought us to focus our attention to the results of these two educational stages henceforth in comparison with the overall results, where appropriate.

If we analyze Figure 6, we can see that there is no clear dominance in the first two decades in terms of the paper's objective (3 of 'ideas diagnosis' versus 4 of 'teaching proposals'). However, from the 1990s onwards, the number of papers that propose and develop 'teaching proposals' is much higher than 'ideas diagnosis' (6 of 'ideas diagnosis' versus 45 of 'teaching proposals').

According to educational level, we can observe that the papers focusing exclusively on diagnosing ideas in recent decades belong practically in their entirety to the Primary Education level, whereas for Secondary Education this objective was concentrated in decades prior to 1990. This appears to indicate that once students' ideas were known, the research seems to focus on carrying out teaching proposals for this educational level.

Focusing on the objective 'Teaching proposal', the first thing to draw attention to when reviewing Figure 6 is that the first teaching proposals for Primary Education appear from the 90s. The tradition of proposing sequences or activities for Secondary students is older, with papers with this objective appearing from the 70s. In Secondary Education, the greatest number of papers is concentrated in the decades of 2000 and 2010 (17 and 10, respectively), coinciding with the greatest number of papers published on floating and sinking. This fact can be related not so much to a temporal increased of the interest in this particular topic than to a rise in journals specialising in SE and an increase production in the field.

In the following section we show what the main alternative conceptions are that have been found in scientific literature on the phenomena of floating and sinking, which can be linked to the 'Ideas diagnosis' objective.

4.4.2. What alternative conceptions do students present regarding the phenomena of floating and sinking?

As we said in previous sections, the systematic literature review that we propose here aims to address the path a teacher or researcher would take to teach the phenomena of floating and sinking. In this sense, our review of alternative conceptions of the phenomena of floating and sinking aims at obtaining information for the improvement of teaching in this subject and, in this way, to inspire fruitful teaching strategies. It wouldn't be, therefore, a question of offering a list of ideas in order to overcome or change them, but to help teachers to select contexts and questions relevant to this subject, to predict and understand the answers they will obtain from students and to foresee the obstacles they will encounter in the construction of explanations, regardless of whether they are based on the idea of density or the model of forces (Driver, 1986; Martínez Torregorosa et al., 1999).

This approach responds to the fact that, despite the multitude of papers that try to identify students' ideas about the phenomena of floating and sinking (which we will analyze in this section), we have detected that there are difficulties in delving into the reasoning behind these ideas. Thus, the first step we have carried out, which is characterized by a catalogue perspective, has been to identify the main explanations given by students about the phenomena of floating and sinking through the 16 papers categorized as 'ideas diagnosis' and forming part of our systematic literature review (Table 2). As a second step, and following an interpretative perspective, we have grouped them in order to reflect on what these explanations could be based on, for which we have used not only the 16 papers cited above, but also others outside our systematic literature review (for instance, papers in Spanish) since we consider that they provide us with the necessary theoretical basis for the analysis of alternative student conceptions.

4.4.2.1. Main alternative conceptions of the phenomena of floating and sinking

Thanks to the systematic literature review presented here, with 16 papers devoted exclusively to the search for alternative conceptions, we have been able to select the main alternative conceptions in relation to the phenomena of floating and sinking. Table 2 summarizes these alternative conceptions, taking into account the following aspects: 1) focus (if they are centered on the fluid or object; 2) the specific variable we are taking into account (e.g., mass, volume, material or property of the object, etc.); 3) the misconception presented by the students (we have not taken into account any criteria when sorting them in the table, other than that they are related to the fluid or object and a specific variable); 4) the papers where they appear; 5) the methodology used to obtain these misconceptions; and 6) specific examples. On the other hand, we present Figure 7, where the difficulties/misconceptions that appear in Table 2 are shown more schematically.

Table 2. Compilation of alternative conceptions, paper/s where it/they appears, methodology to find them and example

Focus	Studied variable	Students' ideas	Papers	Methodology	Example
Fluid		Any object inserted into a sticky liquid will float	(Yin et al., 2008)	Pre-post test – 1002 middle school students	*Misconception X: sticky liquid makes things float*
		The depth at which an object is found in a fluid marks its difficulty/ease of floating/sinking	(Loverude et al., 2003)	Written problems – 2000 university students	*Tendency to relate the positions of objects to the forces exerted on them*
		The amount of water affects the buoyancy of objects	(***Kohn, 1993***[1]; Larsson, 2016; Piaget & Inhelder, 1974; Yin et al., 2008)	20 college students and 28 children – Questions and experiments	*For example, a child may claim that a piece of clay that sinks in a bucket should floating a larger body of water*
Object	Mass	Confusion between the concepts of mass and weight	(Esprivalo Harrell & Subramaniam, 2014)	Pre/post face-to-face interviews and pre/post concepts maps (Cmaps) – 63 pre-service teachers	*It should not go unnoticed that mass/weight confusion*
		Association between heavy/light objects with buoyancy: heavy objects sink, light objects float	(Flores Camacho & Gallegos Cazares, 1998; Havu-Nuutinen, 2005; Hsin & Wu, 2011; Ioannides & Kakana, 2001; Kohn, 1993; Larsson, 2016; Parker & Heywood, 2000; Piaget & Inhelder, 1974; Rowell & Dawson, 1977a; Teo et al., 2017)	Four science activities provided to students – 11 children	*When asked to predict which objects would float or sink, the children unanimously agreed that heavy objects would sink and light objects would float*

[1] To indicate the paper from which the example was taken, the author(s) are shown in bold italics.

	Association between volume of an object and buoyancy: objects of greater volume sink and those of lesser volume float	(***Flores Camacho & Gallegos Cazares, 1998;*** Hsin & Wu, 2011; Potvin & Cyr, 2017)	A questionnaire and an interview– 314 High School students	*An object floats as a function of its volume*
Material or property of the object	The hardness of the material affects its buoyancy	(Teo et al., 2017; Yin et al., 2008)	Pre-post test – 1002 middle school students	*Misconception VII: Hard things sink; soft things float*
	Difficulty in understanding density as an intensive property	(Dawkins et al., 2008; ***Esprivalo Harrell & Subramaniam, 2014***)	Pre/post face-to-face interviews and pre/post concepts maps (Cmaps) – 63 pre-service teachers	*Very few participants provided any data that suggested an understanding that density is an intensive property of matter*
	Memorization of the density formula but difficulty in understanding its meaning	(***Dawkins et al., 2008;*** Esprivalo Harrell & Subramaniam, 2014; Gennaro, 1981; Ginns & Watters, 1995; Shaw & Stepans, 2003)	Lesson-planning task and an interview – 7 pre-service teachers	*Even when students can cite definitions and formulas of science ratio concepts, they do not necessarily understand the meanings or know how to handle calculations involving such relationships*
	Association between air quantity and buoyancy: the higher the air quantity, the easier it is to float	(Ginns & Watters, 1995; Havu-Nuutinen, 2005; Larsson, 2016; Parker & Heywood, 2000; Potvin & Cyr, 2017; Rowell & Dawson, 1977a; Yin et al., 2008)	Pre-interview/instructional process/post-interview – 10 pre-schoolers	*Air, besides the weight of the object, seemed to be a fundamental reason for floating and sinking*
	Association between hollow objects and buoyancy	(Havu-Nuutinen, 2005; Ioannides & Kakana, 2001; Parker & Heywood, 2000; Rowell & Dawson, 1977a; Yin et al., 2008)	Pre-post test – 1002 middle school students	*Misconception II: Hollow things float; things with air in them float.*

Object shape	Association between flat objects and buoyancy: flat objects float	(Yin et al., 2008)	Pre-post test – 1002 middle school students	*Misconception IV: Flat things float*
	Association between vertical/horizontal objects and buoyancy: vertical objects sink and horizontal objects float	(Yin et al., 2008)	Pre-post test – 1002 middle school students	*Misconception VI: Vertical things sink; horizontal things float*
Object position	The mass of an object varies according to the way it is introduced	(Hewson, 1986)	Clinical interviews throw a task – 40 high school students	*The object has a different weight according to how you put it (in the water). When you put it (edge on) it has more weight*
Interactions between forces	Forces as a property of the object	(***Hewson, 1986;*** Larsson, 2016)	Clinical interviews throw a task – 40 high school students	*Objects have force/power/strength/energy*
	Existence of a single force: buoyant	(Loverude et al., 2003)	Written problems – 2000 university students	*Failure to consider all the variables: A number of students mentioned only the different volumes displaced in the different liquids. For example, in answering the question in Fig. 6, one student wrote, "We know the buoyant force on D is greater because more amount of liquid is displaced." Other students mentioned only the fluid densities and concluded that the buoyant force is greater on the block in the more dense liquid.*
	Difficulties in calculating the buoyant force value	(Gennaro, 1981; ***Loverude et al., 2003***)	Written problems – 2000 university students	*A small but significant fraction of students referred to the masses of the objects, not their volumes. For example, in answering the problem in Fig. 4, one student wrote: "The buoyant force on C is less than that of A & B—it displaces less water due to its smaller mass."*

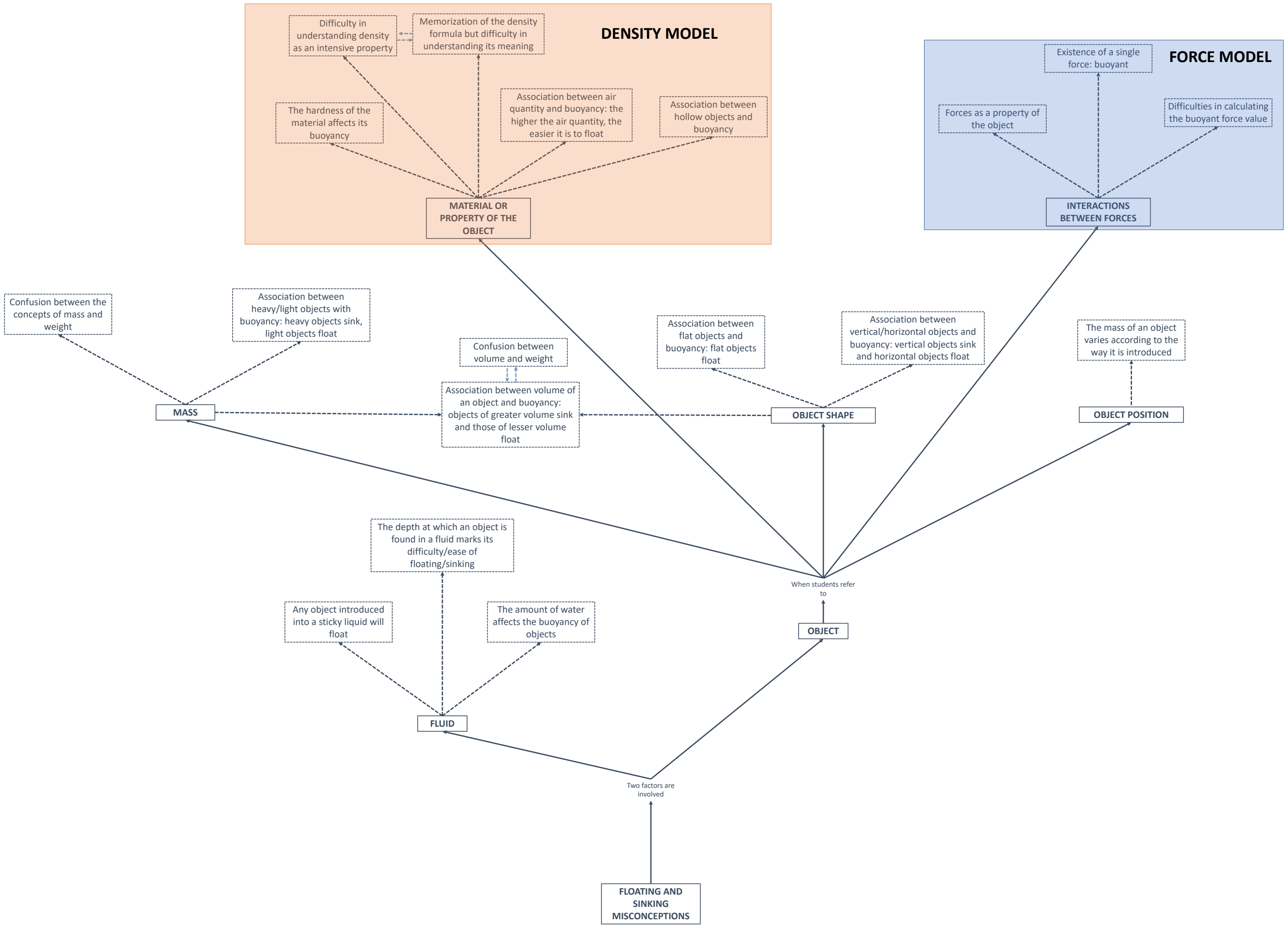


Figure 7. Outline of alternative conceptions on the phenomena of floating and sinking

4.4.2.2. Analysis of the alternative conceptions

In this section we go beyond the description of alternative conceptions, trying to interpret what lies 'behind' them. For that purpose, we follow the structure presented in Table 2 and Figure 7, so that we divide this section according to the focus and variable and the students' ideas. It is important to note that, for the analysis and interpretation of these ideas, we do not use only the 16 papers of the systematic literature review but also others that have been of interest to us for the analysis.

Both the object and the fluid are involved in the phenomena of floating and sinking. However, when the students propose possible explanations, they only focus on one of them, which could be interpreted as a functional reduction. This concept refers to the common reasoning tendency whereby a physical quantity that depends on many variables is explained on the basis of one, i.e., monoconceptual (Rozier & Viennot, 1991) or sequential reasoning (Jiménez-Liso et al., 2003). In the case of flotation, there are few occasions in which students focus their attention on the fluid and implicitly consider that the object is always the same, while, for the most part, students focus their attention on the object and implicitly think that the fluid is always the same, usually water.

4.4.2.2.1. Object

As we have been able to observe in Table 2, most of the analysed papers show student explanations centered on the object (always implicitly considering water as a fluid). In the following, we break down these explanations.

Material or property of the object. A first aspect to take into account is that, on certain occasions, students do not specify which property of the material they are taking into account. However, most of the times when they cite the material they implicitly refer to density. An example of this is when they refer to hardness: hard materials sink and soft materials float (Teo et al., 2017; Yin et al., 2008). This idea could be linked to how concentrated the objects in question are and, therefore, to density (although they do not yet have that concept constructed). Likewise, when they do explicitly refer to density, it could be an academic answer rather than a personal explanation because, as the scientific literature shows, students have difficulties to consider it as an intensive property of the object (Dawkins et al., 2008; Esprivalo Harrell & Subramaniam, 2014) and even if they know perfectly well the formula associated with density ($d=m/v$), they do not know its meaning in a profound way (Dawkins et al., 2008; Esprivalo Harrell & Subramaniam, 2014; Gennaro, 1981; Ginns & Watters, 1995; Shaw & Stepans, 2003).

On other occasions students associate the amount of air inside an object with floating and sinking: an object that contains a lot of air inside will have an easier time floating (Ginns & Watters, 1995; Havu-Nuutinen, 2005; Larsson, 2016; Parker & Heywood, 2000; Potvin & Cyr, 2017; Rowell & Dawson, 1977a; Yin et al., 2008). This, moreover, could be associated with the idea that materials with holes float even if they are filled (Havu-Nuutinen, 2005; Ioannides & Kakana, 2001; Parker & Heywood, 2000; Rowell & Dawson, 1977a; Yin et al., 2008). The origin of this idea could be in the students' own experience as swimmers or with empty jars. Similarly, it could also be associated with the idea found by Hewson (1986), from which his students considered that mass is a characteristic that is not present in all objects, associating it only to solids and liquids, as long as these could be seen and felt. A paradigmatic example of this conception would be the phrase presented by a student of Hewson (1986), who affirms that *always the curly things and those that are made out of plastic are floating... They haven't got weight... they cannot sink.* Likewise, the fact that the students considered that not all solid or liquid objects have mass, but only those that can be seen and felt, is associated, in turn, with the idea that matter is not continuous, but ceases to exist when it is not visible or palpable (Smith et al., 1997). This would mean, therefore, that air or a solid object divided multiple times (until it is not seen or felt) would not be matter.

Mass. From the scientific point of view we know that mass and weight are two different magnitudes (one scalar, property of the object; the other vector, measure of the interaction between the object and the planet Earth). However, students use it interchangeably (Esprivalo Harrell & Subramaniam, 2014) and it is even a justified didactic option in early stages (not in vain, the modulus of both magnitudes on the Earth's surface is proportional). It is important to note that, although mass or weight is used interchangeably by students, they are understanding it as a property of the object and not as a measure of Earth-object interaction.

One of the alternative conceptions related to mass is the one that relates heavy and light objects with floating and sinking: heavy objects sink, while light objects float (Hsin & Wu, 2011; Kohn, 1993; Larsson, 2016; Parker & Heywood, 2000; Piaget & Inhelder, 1974; Rowell & Dawson, 1977; Teo et al., 2017). This explanation could be interpreted as a new functional reduction, where weight is linked to a given volume (in particular for a volume of the order of magnitude of hands), and, therefore, they would be talking about density (m/v). Likewise, this explanation could also be based on the general idea of weight as a tendency to go downward: the natural state of objects is the ground, so the greater the weight, the faster it reaches the ground.

Another alternative conception is that in which volume is used to explain floating or sinking: objects with greater volume sink, while those with less float (Flores Camacho & Gallegos Cazares, 1998; Hsin & Wu, 2011; Potvin & Cyr, 2017). It is possible that this idea is the same as the one expressed in the previous paragraph because, according to the scientific literature, there is confusion between the terms volume and weight (Kohn, 1993).

Object shape/position. Other alternative conceptions found in the scientific literature refer to the shape or position of the object. For example, in their research, Yin et al. (2008) found that students associated flat objects with floating and, in the same sense, that it was easier to float when the same object was horizontal than when it was vertical (i.e., when the flat object is placed on its edge, it would sink). This idea could have its origin in the generalization of a personal experience and perception, since some objects, when placed on the surface of the fluid, remain on it without 'breaking' it, which is identified by many students with floating. It could also be due to the students' idea that the mass or weight of an object does not always have the same value, but varies depending on the conditions. One of these conditions refers to the position in which the object is placed within the fluid. For example, according to a student of Hewson (1986), *the object has a different weight according to how you put it (in the water). When you put it (edge on) it has more weight.*

Interactions between forces. None of the explanations presented so far on the phenomena of floating and sinking allude to the central idea of the interaction model (forces), i.e., that the cause of what happens to the object is not its properties but what is done to the object in question (and that action is mutual). So, we could say that all explanations are centered on the properties of the object or fluid, thus responding to a common feature of everyday thinking: focusing on properties rather than on interactions (Driver, 1986). However, it is important to remark that some works have indeed tried to find out what are the students' ideas in relation to the forces model to explain the floating and sinking of objects (Hewson, 1986; Larsson, 2016; Loverude et al., 2003; Parker & Heywood, 2000).

One of the ideas that appear among students in relation to the interactions model is that they consider force as a property of the object and, therefore, when they are asked to reason in terms of weight or buoyant force they continue to do so from a property perspective (Hewson, 1986; Larsson, 2016). On the other hand, they do not understand the phenomena of floating and sinking in terms of comparison between weight and buoyant force (Melo Niño et al., 2016) but focus their attention on buoyant force (Loverude et al., 2003). This could be due to the fact that, understanding that the natural state of the object is to be on the ground, it is only necessary to explain what can propel it to the surface or prevent it from sinking.

In relation to the value of the buoyant force, the students present multiple alternative conceptions: (a) it depends on the weight of the object and not on its volume (Gennaro, 1981), which could be associated with the idea that the displaced volume depends on the weight of the object (Bullejos de la Higuera & Sampedro Villasán, 1990; Palacios Díaz & Criado García-Legaz, 2016) ; b) depends on the total volume of the object and not on its submerged volume or volume of the displaced fluid; c) depends on the position of the object within the fluid, which could be linked to the association of the buoyant with the absolute pressure and not with the difference of pressures between the ends of the object (Loverude et al., 2003).

4.4.2.2.2. Fluid

If we focus on the explanations provided by students that focus on fluids, it should be noted that all the papers analyzed contextualize liquids and ignore gases. Considering the total sample, we did find some papers that use gas as context (Brinks & Brinks, 1994; Miano, 1995; Radovanović & Sliško, 2013) but these papers were about teaching and learning sequences and did not analysed student's ideas.

In this context where the fluid is the focus of the students' attention, Yin et al. (2008) highlighted the idea that any object introduced in a sticky liquid would float, thus understanding that we would be dealing with a generalized behaviour of the liquid (no object sinks in any sticky liquid). The term sticky liquid could be linked to the density of the liquid, but also to the fact that the surface is difficult to break, alluding to surface tension. To understand the latter explanation, we have to keep in mind that many students consider an object that floats to be entirely on the surface of the fluid and not partially submerged.

On the other hand, Loverude et al. (2003) found in their undergraduate students that 30% of the introductory students and 15% of the second-year students associated the position of an object with greater or lesser difficulty in sinking. For example, if an object is at the bottom of a bucket filled with water (i.e., when the object is sunk) it will be more difficult to sink than one that is at the top of the bucket. Likewise, students of different ages and contexts concurred in interpreting that the amount of water affects the buoyancy of objects: the more water, the more an object will float (Larsson, 2016; Piaget & Inhelder, 1974; Yin et al., 2008). In both cases students might be thinking in terms of absolute pressure (and not in terms of fluid pressure difference between the ends of the object), that it is pressure that causes upward thrust such that the greater the depth, the greater the pressure and the greater the upward thrust.

4.4.3. What are the characteristics of the teaching proposals on the topic of floating and sinking?

In this subsection we spell out the following aspects relating to the teaching proposals that appear in the research papers of our sample: 1) concepts addressed; 2) testing objects used; 3) teaching approaches employed; 4) Existence of implementation of the proposals and evaluation of their effectiveness. To do so, we analyse the sub-sample of papers corresponding to the 'teaching proposal' objective (N=55), focusing on those papers in the Primary and Secondary educational levels (N= 49).

4.4.3.1. Which concepts are included in the teaching proposals on floating and sinking?

The conceptual analysis of the papers on floating and sinking reveal that teaching and learning of this topic involves two main conceptual frameworks: based on the concept of density and based on the concepts of forces. In the case of density, we have found that the teaching and learning proposals that focus on this concept include the following as sub-concepts: mass, volume, the concept of density itself, relative density and density as a property of matter. Regarding the concept of forces, the related sub-concepts are: buoyant force, weight force and equilibrium of forces. Some fragments that helped us identify that a paper addressed the phenomena of floating and sinking with the concept of density are those seen in Figures 8 and 9. Likewise, in Figures 10 and 11 we show two examples relating to papers that explain their focus on forces.

> area, or between amount of sugar added and the concentration of the solution. The concept of density was first introduced as weight per unit length when students had to identify rods that were made from the same material given a set of rods of different lengths made from plastic, aluminum, copper, and steel. This was followed by a

Figure 8. Fragment obtained from paper by Hashweh (2016)

> Having shown that the values of the ratio of weight/volume were closely similar for the six bars, and given reasons why they would be unlikely to be *exactly* the same in these experiments, the term "density" was introduced, discussed, and noted. As expected, the

Figure 9. Fragment obtained from paper by Rowell and Dawson (1977)

> The first cohort started the sinking and floating unit by identifying and discussing the forces and directions exerted on objects floating, suspending, or sinking in water.

Figure 10. Fragment obtained from paper by Shen et al. (2015)

> and the apparent weight loss recorded. This activity also led to a discussion of forces acting on a floating object.

Figure 11. Fragment obtained from paper by (Greenwood, 1996)

To analyse the relative importance/presence of both approaches in the selected research papers, we have used two types of graphical representations. The first type of graphic, represented in Figures 12, 13 and 14, are done for both the global sample and for each educational level, respectively. In these graphs, the inner circle shows the distribution by frequency of the concepts that appear in the papers, divided in into three thematic blocks: including concepts related to density, to forces or to both (combination of concepts related to forces and density). For the second circle, we represent the distribution of papers whose teaching proposals focus on one, two or three (or more) sub-concepts. That is, we show which is the conceptual density of each teaching proposal. In the outer concentric circle, we indicate the actual concepts focused on each of the teaching proposals described in the papers. For instance, in this extract (*In this activity, students measure the mass of several 12-ounce diet and regular soda cans;* Sanger, 2011) we interpreted the authors focused exclusively on the mass property ('M' in the graph). Other example, *students are asked to calculate the density of the soda cans using the mass of each soda can and the average volume of displaced water* (Sanger et al., 2009), shows how the authors not only take into account the mass but also the volume of the object (M/V in the graph; Figures 12, 13 and 14) to calculate the density of the said object.

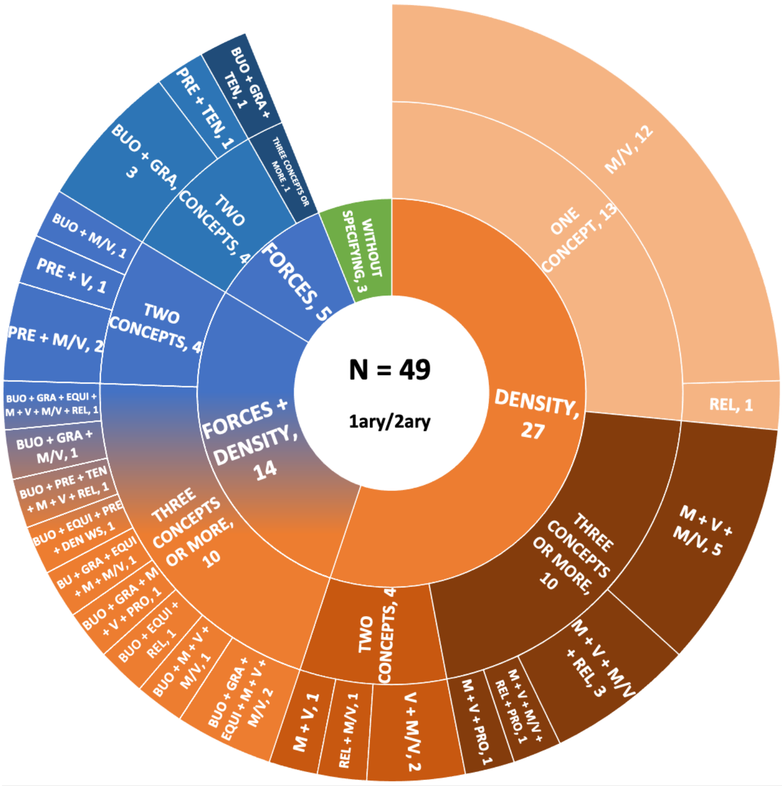


Figure 12. Conceptual focus of the floating and sinking research-based teaching and learning sequences (global analysis). Codes used in the graph: 1) buoyant force: BUO; 2) gravity force: GRA; 3) equilibrium: EQUI; 4) presion: PRE; 5) tension: TEN; 6) mass: M; 7) volume: V; 8) density: M/V; 9) density without specifying: DEN WS; 10) relative density: REL; 11) property: PRO.

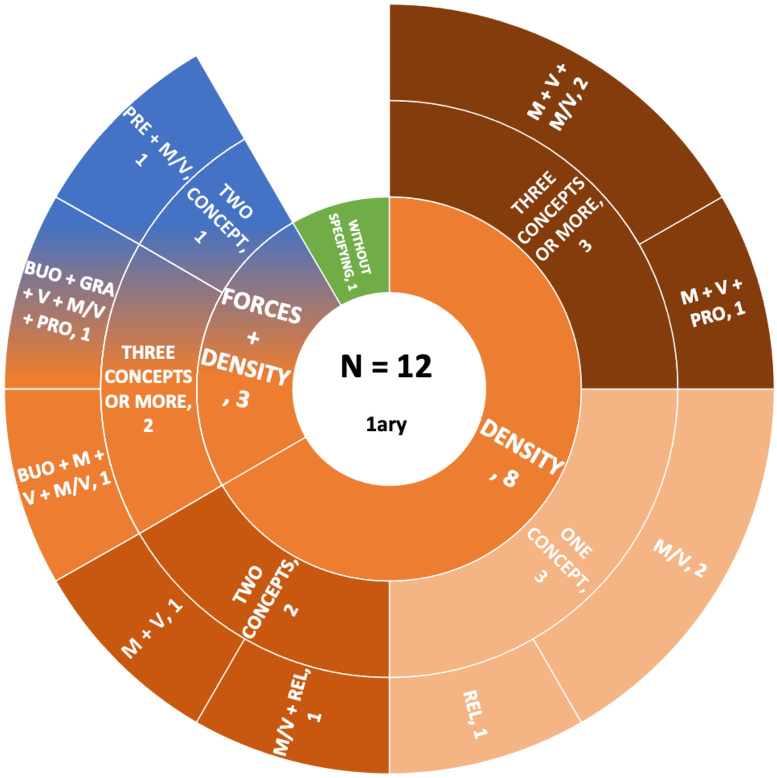


Figure 13. Conceptual focus of the floating and sinking research-based teaching and learning sequences (analysis of Primary level). Codes used in the graph: 1) buoyant force: BUO; 2) gravity force: GRA; 3) equilibrium: EQUI; 4) presion: PRE; 5) tension: TEN; 6) mass: M; 7) volume: V; 8) density: M/V; 9) density without specifying: DEN WS; 10) relative density: REL; 11) property: PRO.

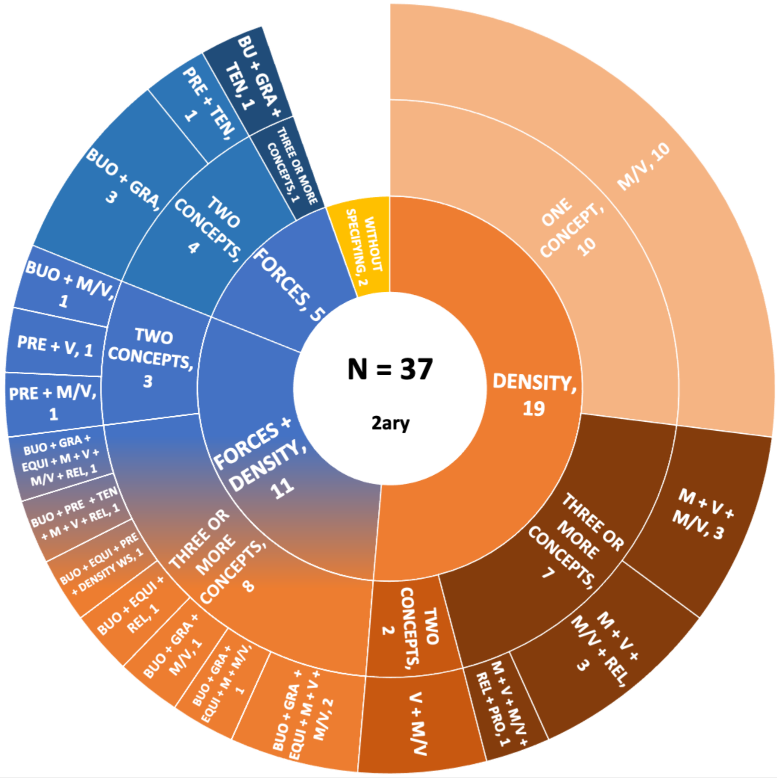


Figure 14. Conceptual focus of the floating and sinking research-based teaching and learning sequences (analysis of Secondary level). Codes used in the graph: 1) buoyant force: BUO; 2) gravity force: GRA; 3) equilibrium: EQUI; 4) presion: PRE; 5) tension: TEN; 6) mass: M; 7) volume: V; 8) density: M/V; 9) density without specifying: DEN WS; 10) relative density: REL; 11) property: PRO

These graphics show that the majority of the papers (55%, Figure 12) deal with floating and sinking exclusively from the perspective of density, being more numerous in Primary Education papers (66%, Figure 13) than in Secondary Education papers (51%, Figure 14). The papers that focus exclusively on the concept of forces (5, all for Secondary Education) or which combine both perspectives (14, Secondary Education on the whole), are scarce. All of the Primary Education proposals tackle floating and sinking from a perspective of density and only some of them (3) combine this concept with forces. Likewise, there is only one paper that includes pressure (Audet, 1997) and another that does so in relation to buoyant-weight forces (Hardy et al., 2006). The majority of the teaching proposals for Secondary Education (10) on density focus on a single content (M/V) (Xu & Clarke, 2012) or propose working on three or more contents (7). In those with a focus on forces, the majority frequency of papers includes buoyant force + weight force (3) (Sconyers & Trautwein, 2000).

As this distribution fails to shed sufficient light on relationships between the involved concepts and sub-concepts, we have included a second type of graphic based on network visualization (Figures 15 and 16) that will allow us to make visible / show such relationships. For the development of these network visualizations we have used the GEPHI software program, where the greater size of the nodes and words indicates a bigger relationship between the concepts and where the thickness of the lines is proportional to the number of papers that relate both concepts. With the aim of viewing differences between the main concepts and the relationships between them by educational level, we have graphically represented the two samples for Primary (N=12) and Secondary Education (N=37).

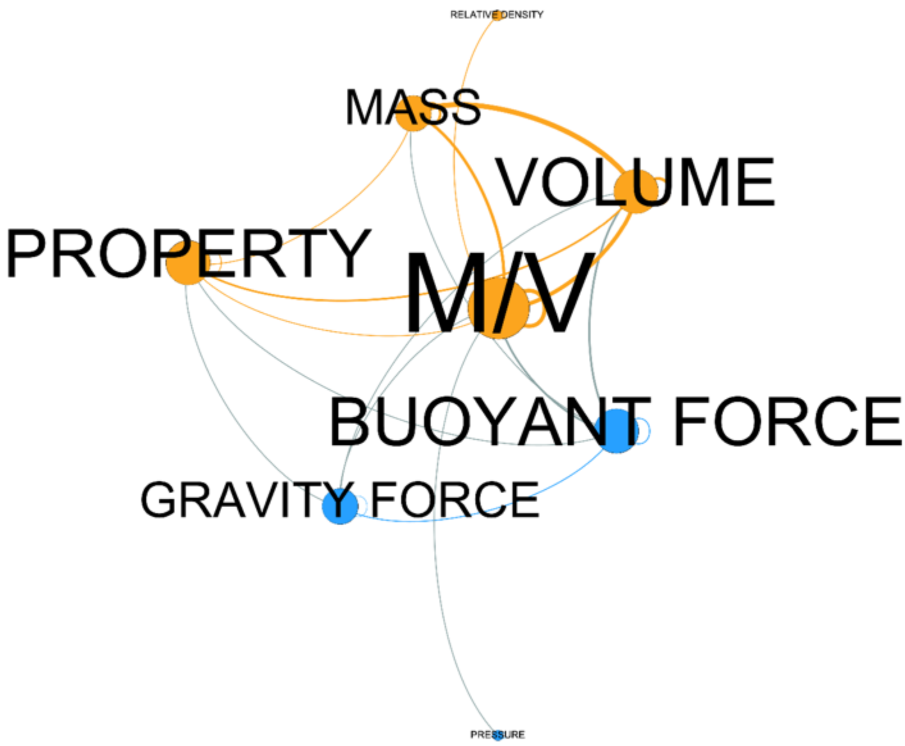


Figure 15. Concept network (analysis of Primary level)

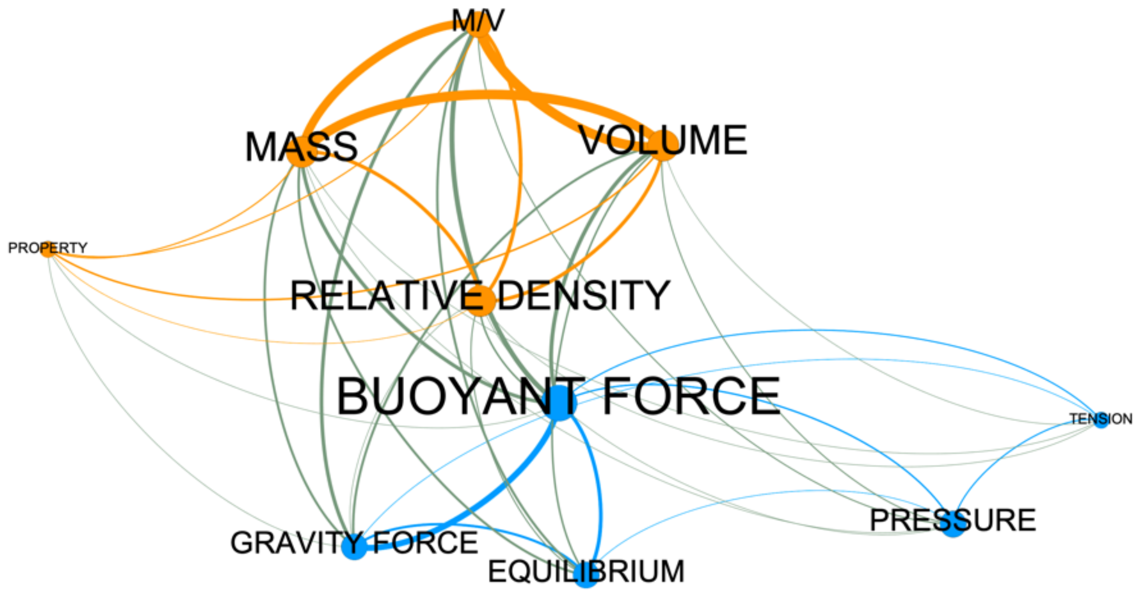


Figure 16. Concept network (analysis of Secondary level)

In the network visualizations (Figures 15 and 16) we can observe that the teaching proposals on floating and sinking are very different at conceptual level for Primary and Secondary Education. In Primary Education proposals we observe that the relationships of concepts with greater frecuency make reference to mass, volume and their relationship (m/v) (Figure 15; N=12). However, the number of times that the connections between buoyant force and weight force are repeated is far lower and the concept of equilibrium of forces disappears. Apart from this, certain concepts passed unnoticed, such as tension, pressure and density as a property of matter.

As for the papers related to Secondary Education (Figure 16; N=37), the structure that appears in Primary Education is more or less repeated, with mass, volume and their relationship (m/v) standing out (Kireš, 2007; Lee & Kwok, 2010; Sanger et al., 2009). However, unlike what happens in Primary Education, at this educational level the relationships established between buoyant force, weight force and, to a lesser extent, equilibrium stand out (Miano, 1995; Raghavan et al., 1998). Some concepts appear superficially in the Secondary Education content network (Figure 16) such as tension or density as property of materials.

Nevertheless, how are the contents present in Primary and Secondary Education related? Paying our attention to the network regarding Primary Education (Figure 15), the M/V relationship is a central node around which all the others revolve (highest number of relationships considering letter size). Mass and volume are contents that are also widely linked to others, as shown in Figure 15. On the other hand, while relative density in this level is scarcely related to any concept, density as a property of materials is strongly related to others (Hardy et al., 2006; Leuchter et al., 2014). In the forces part, buoyant acquires greater relevance than weight depending on its relationships with other contents (Cuicchi et al., 2003; Hardy et al., 2006), with contents on equilibrium of forces and tension completely disappearing.

Focusing now on Figure 16 (Secondary Education) we can observe that the conceptual contents that have most been related to each other are buoyant force, relative density, mass and volume, which are combined with the totality of the contents proposed in the papers. On a second level, we would find weight force, equilibrium and pressure. Finally, and practically without a combination with other contents, we would speak about tension and density as property of materials (thus their smaller letter size, lower number of lines and thinner lines). It is important to note that, on the one hand, and unlike what happens in Primary Education, relative density is one of the central nodes and, on the other hand, that density as a property of materials is hardly related to any other content.

In accordance with the graphics shown here, the focus on density is the most common for working with the phenomena of floating and sinking, and almost exclusively used in Primary Education The teaching proposals with forces as exclusive concept only appear in papers for Secondary Education, while in Primary Education forces hardly appear (3, Audet, 1997; Cuicchi et al., 2003; Hardy et al., 2006) and if so, are always combined with the density approach. The results of the network visualizations by educational levels reveal differences between the treatment of floating and sinking in papers for Primary Education and those for Secondary Education, discerning a curricular path where Primary Education would have a focus on the descriptive character revolving around the M/V relationship (Hashweh, 2016), whereas in Secondary Education there appears to be an explanatory intentionality, given the greater appearance of concepts such as buoyant force, weight and equilibrium (Gao et al., 2020). In those papers showing a treatment focused exclusively on forces (Radovanović & Sliško, 2013; Sconyers & Trautwein, 2000), everything revolves around the buoyant, with the presence and relationships with force-weight being lesser, or the number of papers with explanatory capacity for equilibrium of forces being lower.

4.4.3.2. Which testing objects prioritise teaching proposals in research papers on floating and sinking?

In this sub-section we have classified and graphically represented by frequencies the papers with floating and sinking teaching proposals depending on the testing objects they use therein, which will give us an idea of the contexts in which the teaching proposals are considered.

In order to classify the different testing objects, we have taken into account whether the materials are of daily nature (irregular, random, chosen by students), such as for example Coca Cola cans, candles, eggs, etc. or more academic ones (ad hoc, regular, intentional and chosen by teachers), with regular shapes such as cubes and spheres serving as an example of the latter. In terms of daily materials, we want to draw attention to the fact that two quite common objects, the boat and the submarine, have been included in the category of daily materials because, despite not being at the easy reach of the students, in the teaching and learning proposals daily materials have been used materials that simulate these objects.

In addition to the objects used for theoretically or empirically testing its buoyancy, we have also analysed the floating and sinking fluid in which these objects are summerged to test their buoyancy, whether this be liquids (in blue; Figures 18, 19 and 20) or gases (in orange; Figures 18, 19 and 20). In order for the reader to be able to visualise some specific elements used in the papers, below we show two testing objects: an academic testing object in the form of a sphere (Figure 17; left) and another daily one represented via a can of Coca Cola (Figure 17; right).

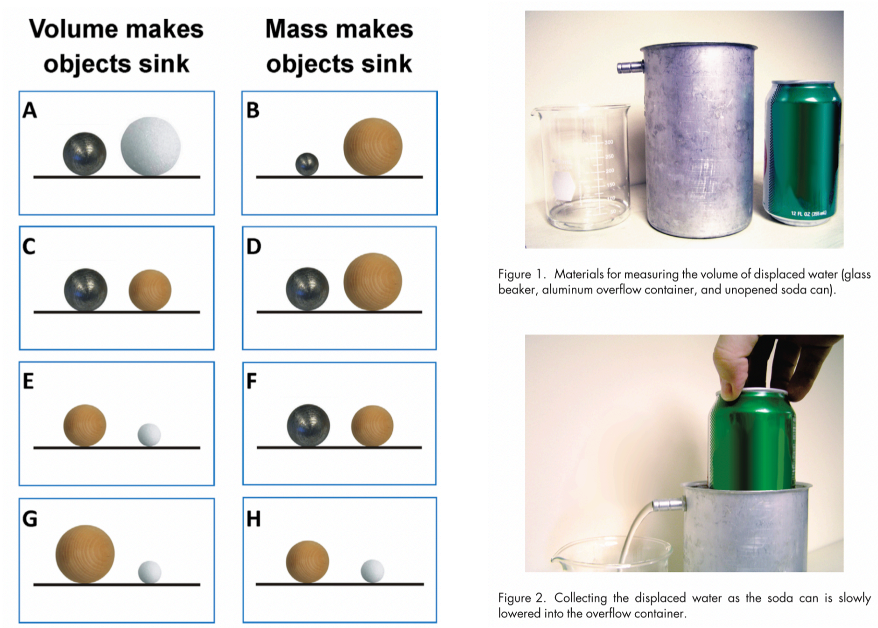


Figure 17. Fragments obtained from Potvin and Cyr (2017, left image) and from Sanger (2011, right image)

In Figures 18, 19 and 20 we show the resulting graphics following classification and categorisation of the different testing objects for the global analysis and regarding the teaching proposals of Primary and Secondary Education.

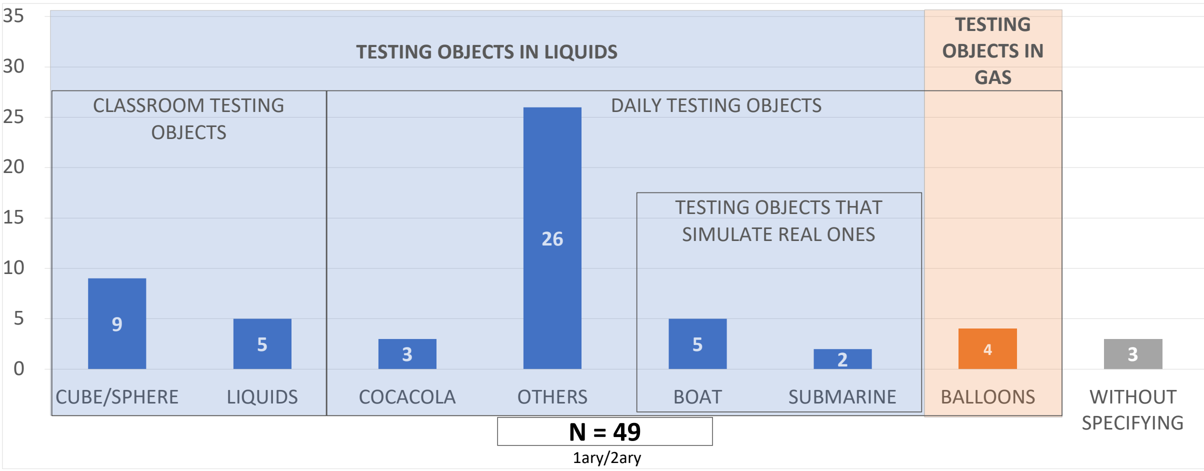


Figure 18. Testing objects (global analysis)

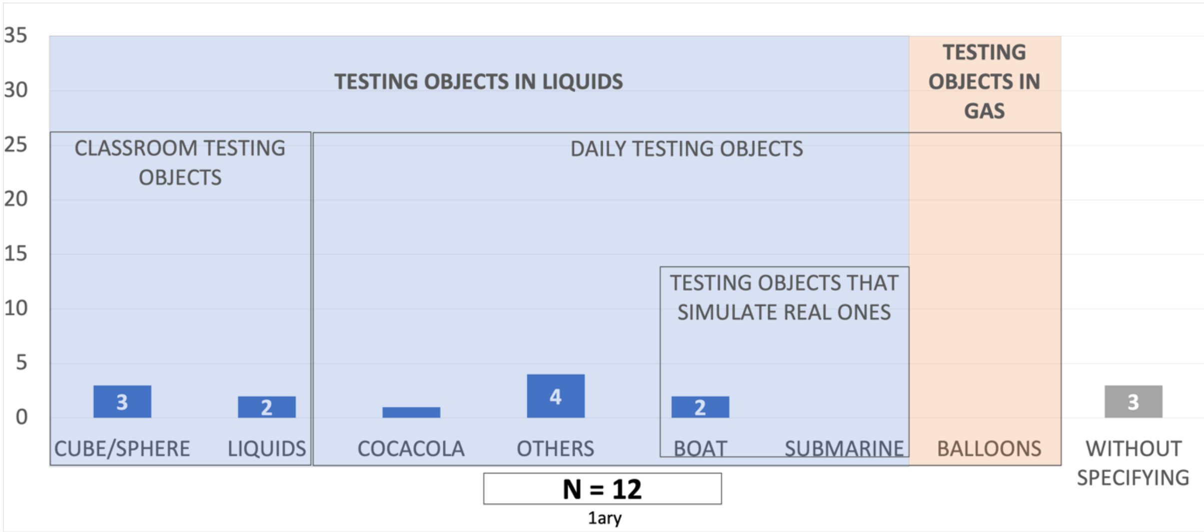


Figure 19. Testing objects (analysis of Primary level)

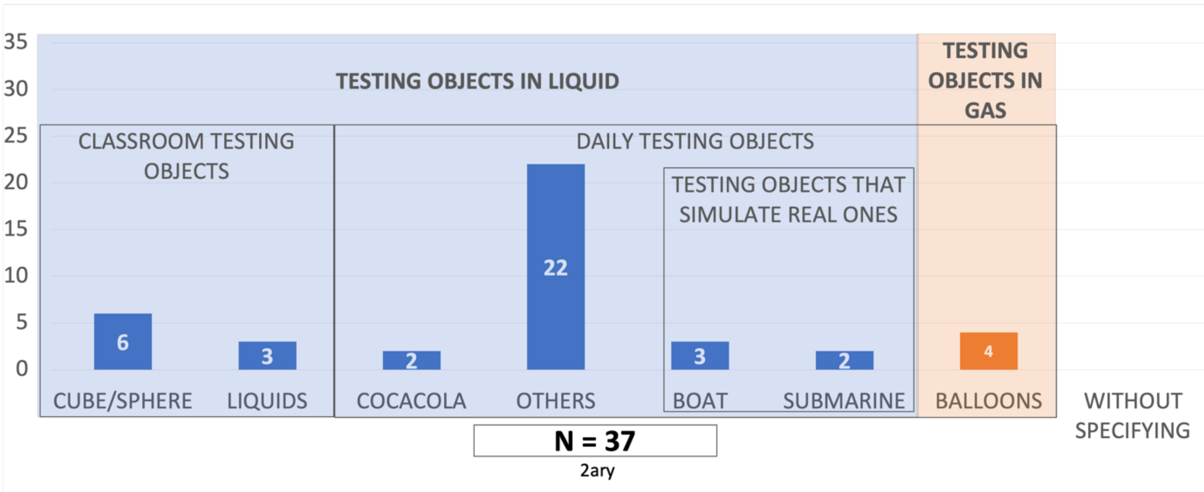


Figure 20. Testing objects (analysis of Secondary level)

Overall (Figure 18) almost the totality of the papers contextualise their teaching proposal with daily objects in liquids (generally in water and sometimes oil, McBride, 2003; Yin et al., 2014).

Just four papers for Secondary Education (Figure 20, Brinks & Brinks, 1994; Miano, 1995; Radovanović & Sliško, 2013; Raghavan et al., 1998) set out their teaching proposals with objects in gases (balloons) for working with floating and sinking.

Only 38% of the objects (both for Primary and Secondary Education) are academic, regular, chosen intentionally (like cubes and spheres), whereas the majority (nearly two-thirds of the papers analysed) use irregular daily objects like candles, eggs, glasses, spoons and corks, all taken into the classroom by teachers.

These results show that in papers on floating and sinking the difficult balance between context and content described in the teaching literature is evident (Kortland, 2007; Martínez-Del Águila & Jiménez-Liso, 2012), and there is emphasis on the decision to contextualise with daily materials compared to the simplified choice of school materials, even though these latter ones would aid the increasing sophistication of students' ideas in construction (Acher et al., 2007).

4.4.3.3. What teaching approaches appear on papers on floating and sinking and how do these approaches evolve along time?

In this sub-section we analyze, on the one hand, which are the predominant teaching approaches in the scientific literature in relation to the topic of floating and sinking (Figures 23, 24 and 25), and, on the other hand, how they have evolved over the decades (Figures 26, 27 and 28).

We have grouped them depending on whether they develop POE (predict-observe-explain) type teaching; guided discovery; conceptual change; inquiry; modeling; argumentation; and direct instruction experiment. For example, in Figures 21 and 22 van Riesen et al. (2018) and Campbell et al. (2011) recognise they are working with inquiry and modeling, respectively.

Domain and learning environment

Students in all conditions worked in an online inquiry learning environment created with the Go-Lab software (Gillet, Rodríguez-Triana, de Jong, Bollen, & Dikke, 2017) revolving around buoyancy and Archimedes' principle. Three versions of the same online inquiry learning environment were created. All environments were organised

Figure 21. Fragment taken from van Riesen et al. (2018)

> lecture and demos. The MBI class was used as the intervention or experimental population and was taught through model-based inquiry instructional strategies whereby students worked in groups of 2–3 students to develop a model of their understanding of buoyancy and used class time to design and test mechanisms for further developing, extending, or refining their original models. The differ-

Figure 22. Fragment taken from Campbell et al. (2011)

Focusing on Figures 23, 24 and 25 we have represented the distribution in frequency of the papers, firstly (inner circle) according to whether they consider separate activities (without sequencing) or sequences or activities and, secondly (outer circle), the distribution of the previously shown teaching approaches.

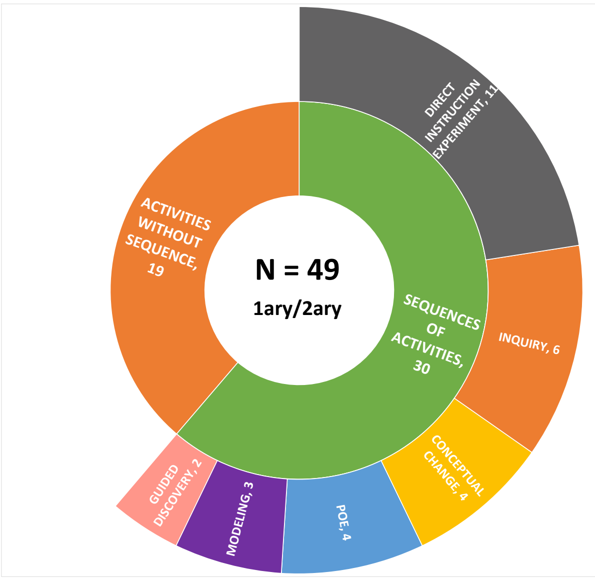


Figure 23. Teaching approaches (global analysis)

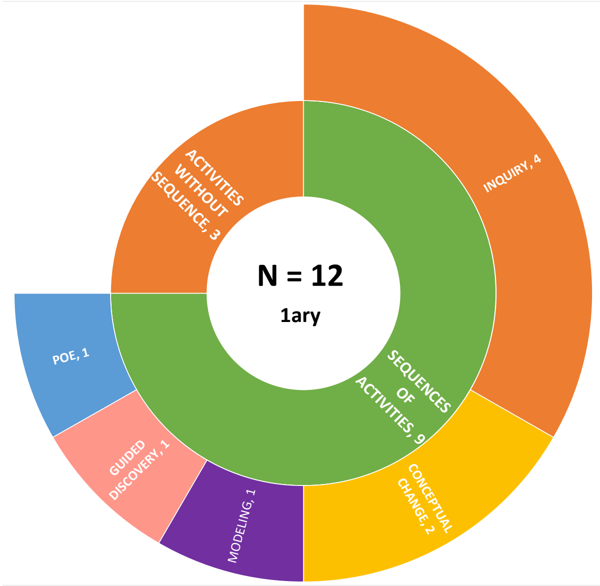


Figure 24. Teaching approaches (analysis of Primary level)

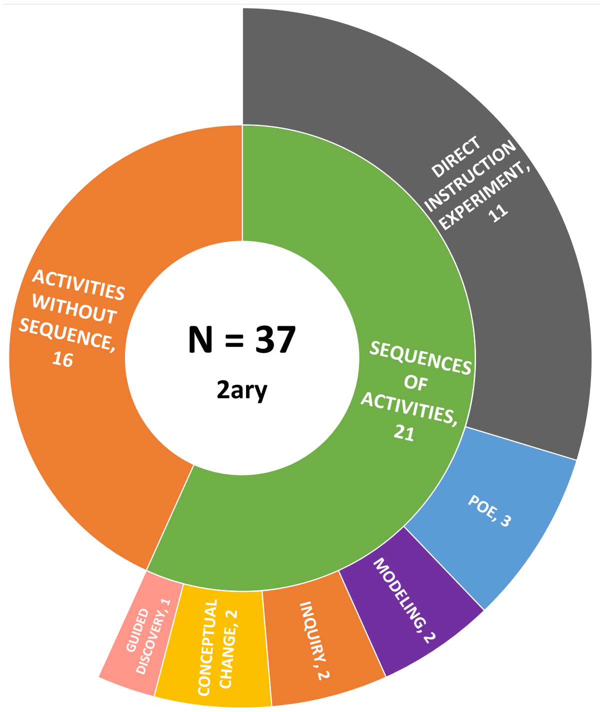


Figure 25. Teaching approaches (analysis of Secondary level)

As we can observe in the three graphics, the majority of papers (62%) propose sequenced activities (complete teaching units, teaching and learning sequences, school projects, etc), compared to those focused on isolated activities (38% of the total), both in Primary (75%; Figure 24) and Secondary Education (56%; Figure 25).

In terms of the teaching approach, almost half of the papers that propose activity sequences on floating and sinking for Primary Education (4 of 9, Figure 24) explain that their approach is inquiry (Kuntzleman, 2015; Turcotte, 2012), followed by proposals of conceptual change (2, Hashweh, 2016). The majority of papers with floating and sinking activity sequences for Secondary Education (11 of 21, Figure 25) present the direct instruction experiment approach, such as for example that presented by McBride (2003), characterised by showing students the procedure to follow in order to do the experiment and, afterwards, puts specific questions to them in order to reach the conclusion of why boats float ('How does the volume of the water displaced by the clay boat compare to the volume displaced by the clay ball?' 'How does the mass of the water displaced by the clay boat compare to the mass displaced by the clay ball?' 'Based on your findings, can you explain why the boat floated and the ball sank?'). This type of proposal is followed by POE type sequences, such as that presented by Radovanović and Sliško (2013), who ask their students to carry out the following steps: they first take a balloon and draw two parallel lines on the neck; secondly, they put water into the balloon and measure the distance between the previously drawn lines; thirdly, they predict what the distance between the lines will be if they put the balloon full of water into a bucket also full of water; fourthly, they observe what occurs and, finally, attempt to give an explanation.

The fact that the majority of the activity sequences are direct instruction experiment, inquiry or POE appears to indicate that the activity sequences put forward focus more on hands-on than minds-on teaching proposals, amongst which would be conceptual change and modelling. We might attribute this fact to the content itself, which has traditionally been taught in manipulative rather than abstract-mental contexts. This concurs with the results of the content analysis that indicated that the papers leant more towards the descriptive perspective regarding density than the more abstract perspective of forces.

In order to analyse if there is an evolution in the teaching approaches used along time, we have also represented the different types of teaching proposals in the different decades encompassing our sample of paper, from 1970 (Figures 26, 27 and 28). Notwithstanding this, we must take into account that to show these representations we have once again reduced the sample. In these specific graphs, we exclusively keep those papers that show sequences of activities (N=30), given we consider that no specific teaching approach appears in activities without sequencing. Thus, in Figures 26, 27 and 28 we show the distribution of papers (in frequencies) of the teaching approaches by decades and educational level (N=9 for Primary and N=21 for Secondary Education).

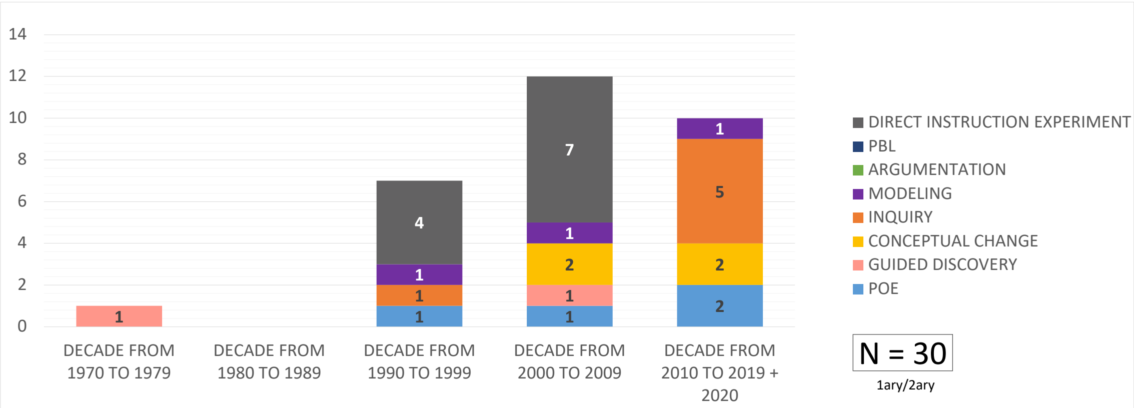


Figure 26. Teaching approaches per decades (global analysis)

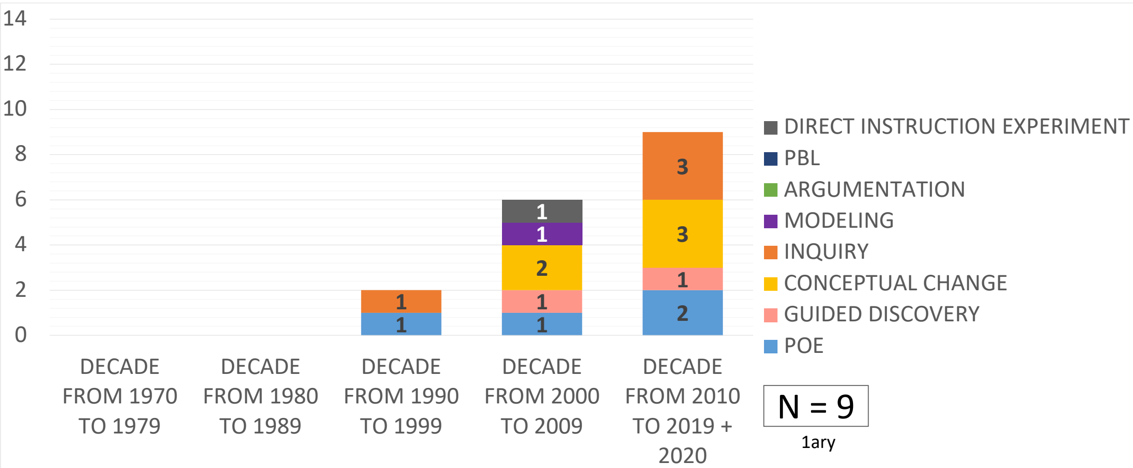


Figure 27. Teaching approaches per decades (analysis of Primary level)

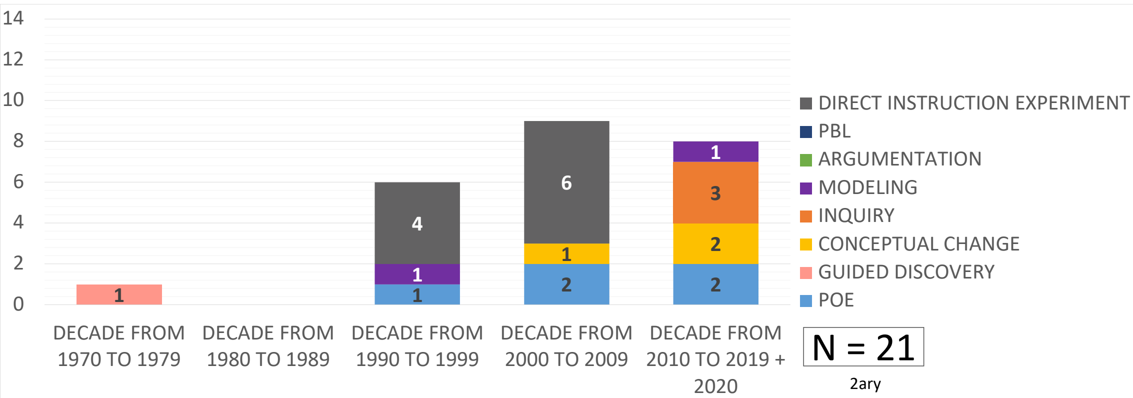


Figure 28. Teaching approaches per decades (analysis of Secondary level)

In the global sample graphic (Figure 26) we can observe, firstly, that there are no activity sequences in the first two decades, therefore no teaching approaches appear apart from one in the 1970s, of guided discovery. In the decades 1990-2009 (11), for the Secondary educational level (Figure 28) the majority teaching approach is the direct instruction experiment, with no paper with this approach being found in the last decade (2010-2020) and only one for Primary Education (Figure 27) in any decade.

In the last decade the inquiry-based teaching approach is the one shown by the greatest number of papers (both for Primary and Secondary Education). We have found papers with POE activity sequences in the three decades and in both educational levels. The percentage of papers with activity sequences with a conceptual change approach is higher in Primary than Secondary Education (3 for Primary Education and 2 for Secondary Education), modelling papers for Secondary Education are sporadic (Campbell et al., 2011; Raghavan et al., 1998) and we have only found one for Primary Education (Kawasaki et al., 2004).

As we have not found papers on floating and sinking for Primary Education until the 1990s, research in this period having started later, the papers show teaching approaches of a more constructivist type, as if they had skipped over the direct instruction experiment approach. In Secondary Education, given that the curricular weight of the content is greater than in Primary Education, the diagnosis of alternative conceptions can be related to the direct instruction experiments teaching approach (no paper for either in the last decade), with the tendency of SE leaning towards studies more focused on students building knowledge through scientific practices.

4.4.3.4. Have the teaching proposals being implemented and/or evaluated?

In this last section we wanted to assess whether or not the teaching proposals presented by the authors were implemented and, in the case of the affirmative, if they have evaluated their impact and how. In this regard, we have taken into account whether such an evaluation assessed the change in students' ideas (either related to scientific contents or with the epistemology of science) or the satisfaction thereof (for further information, Annex II). Thus, Figure 29 shows a paper categorised as evaluating the sequence based on the change of student ideas. In the case of Figure 30, it would be indicating that it is evaluating based on student satisfaction.

> **Results**
>
> Our first analysis addressed whether students had learned from working with the learning environments, and if there was a difference in learning gains between conditions. A one-

Figure 29. Fragment taken from van Riesen et al. (2018)

> ***The students' evaluation of the activity***
>
> In the third part, the students evaluated how much they liked the activity, on the scale of 0 (very little) up to 5 (very much). The evaluation results are shown in table 1.

Figure 30. Fragment taken from Radovanović and Sliško (2013)

In Figures 31, 32 and 33 we maintain the sample of the previous section and, therefore, continue to focus on sequences of activities. With the inner circle we want to show whether or not the papers indicate that they have implemented the teaching proposals and, with the outer circle, on what they focus for evaluating the impact thereof.

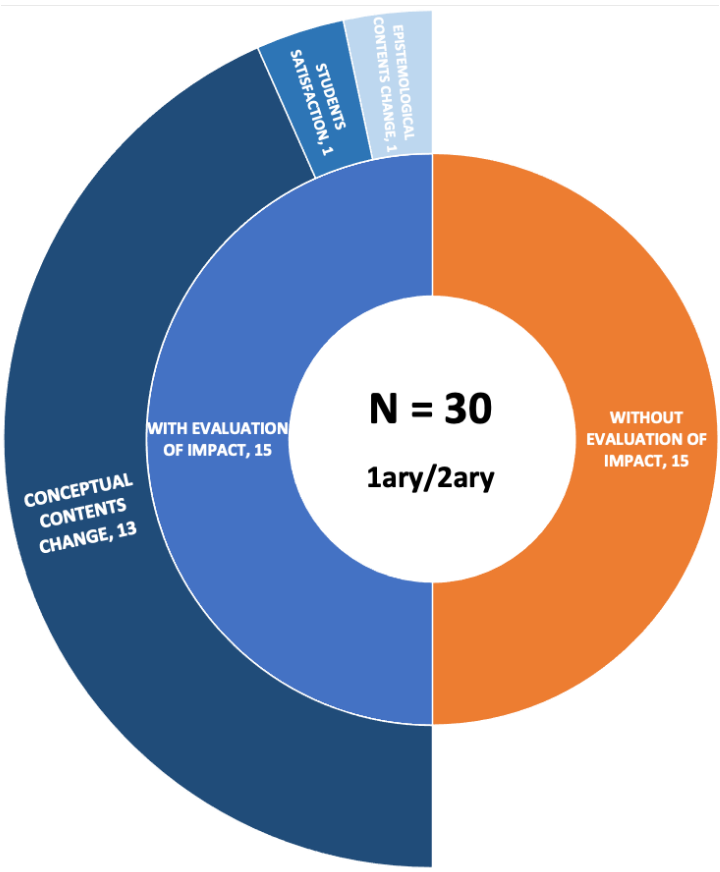


Figure 31. Evaluation of the impact of the teaching proposal (global analysis)

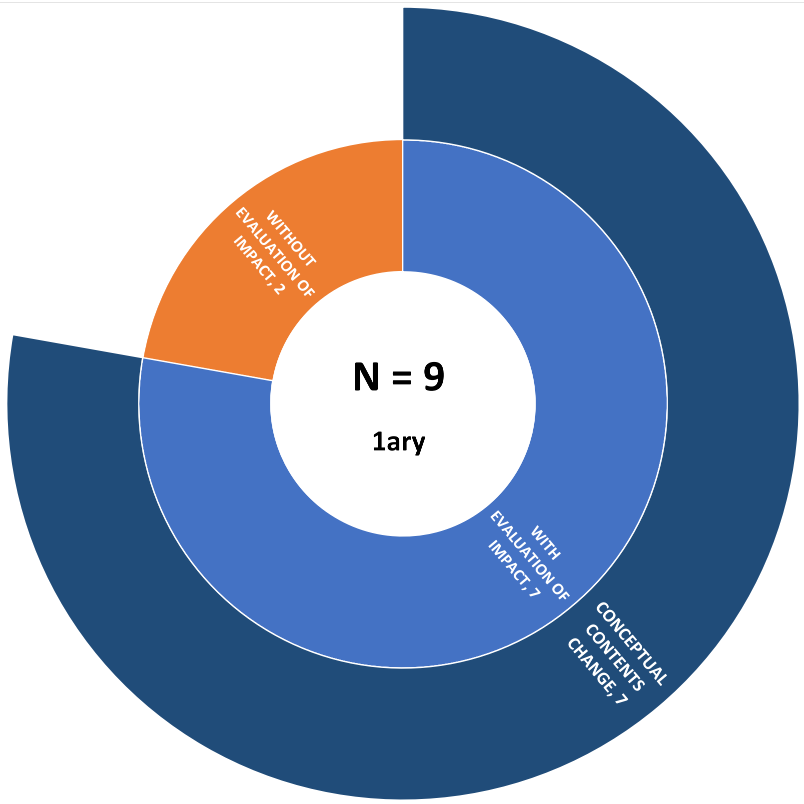


Figure 32. Evaluation of the impact of the teaching proposal (analysis of Primary level)

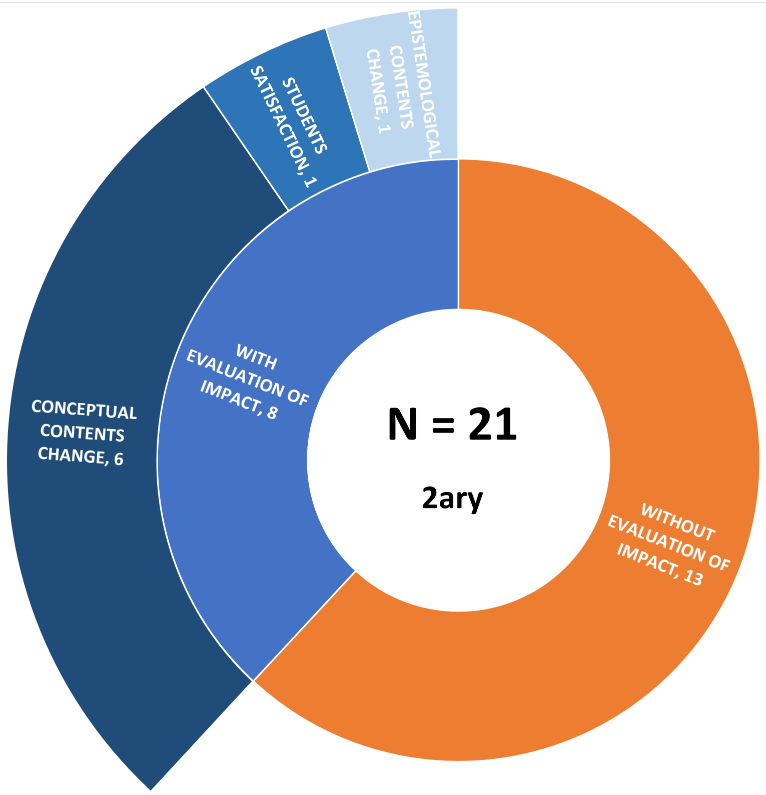


Figure 33. Evaluation of the impact of the teaching proposal (analysis of Secondary level)

The inner concentric circle of the overall graphic (Figure 31) shows that half of the papers proposing activity sequences (15) implement them in practice and also assessed their impact. This percentage is much higher in papers for Primary Education (77%) than in those for Secondary Education (38%). The majority of the papers that do assess the impact of their teaching proposals have the sole objective of showing the change of ideas about floating and sinking displayed by students before and after the implementation. In Secondary Education we find two papers that, furthermore, evaluate student satisfaction (1) or the epistemological change regarding what science is and how it is constructed.

Here we take the time to describe a typical paper in order to exemplify what the evaluation process is: van Riesen et al. (2018) evaluated during the first session (of a total of four) the ideas of students aged 15 on floating and sinking and the principal of Archimedes. Once this was done, during the second and third sessions the students went deeper into the sequence of activities proposed by the authors, using *an online inquiry learning environment created with Go-Lab software* to do so. This software provides sets students a research question (such as, for example *'How do the mass, the volume, and the density of a floating ball influence the amount of water that is displaced in terms of mass and volume?'*), which will be the starting point from which students carry out an inquiry. To this end, they will express their hypotheses, realise experimental designs, draw conclusions relating to floating and sinking and the Archimedes principle, etc., and all via the *online virtual lab: Splash* (virtual space that allows them to vary the mass and volume of the balls, the density of the fluid in which they float, and so on). Finally, in the fourth session, the authors of the paper gave the students the post-test to evaluate whether or not a change of ideas had taken place, it being the same as the one taken in the first session (van Riesen et al., 2018).

In the same way as we have indicated in previous sections (diagnosis vs teaching proposals, teaching approaches), the notably high percentage (77%) of papers for Primary Education which, as well as proposing activity sequences, evaluate them based on the change of ideas of students, could be due to the late commencement of studies in this educational level and to the historical development of the SE which shows greater interest in evaluating the validity of teaching proposals. In Secondary Education, as we found teaching proposals in the initial decades the focus was on offering alternatives without placing particular emphasis on evaluating their effectiveness. The papers that assess teaching proposals for Secondary Education as well as the change of ideas are also focused on the epistemological change (Campbell et al., 2011), which shows the current interest for correlating scientific and epistemological learning.

4.5. Discussion

The results shown appear to indicate that the phenomena of floating and sinking, along with its historical development, shows some characteristics that are idiosyncratic of the topic and others that can be related and linked to the common historical development of SE and which, therefore, could occur in other topics.

The evolution undergone by the objectives set out in the different studies on floating and sinking indicate a development that shows to be similar to that of other domains given that, as suggested by studies focused on SE research trends, the search for alternative conceptions or difficulties that students have as regards the contents of the curriculum reached a peak at the end of the 1990s and the beginning of the 2000s, subsequently being eclipsed by the appearance of new papers concerned, amongst other things, with classroom contexts, learning environment and teaching/learning approaches; in other words, of specific proposals for the classroom (Lin et al., 2019), as has also occurred in the specific case of the topic of floating and sinking.

We could have expected that the long tradition of studies on *ideas diagnosis* would be in short supply after finding the generalised consensus regarding what alternative conceptions and/or difficulties are presented by students of different ages when faced with the sinking or floating phenomena. However, the late incorporation of studies on younger students has meant that they have not disappeared, even for Secondary level, which shows the recurrence of this line of research. Similarly, focusing on new phenomena, such as water pollution by microplastics, could cause to further research on alternative conceptions today.

As far as the conceptual treatment of the teaching proposals presented in the scientific literature is concerned, we could say that there is a substantial difference between the conceptual focus for the Primary Education proposals and those for Secondary Education, and that in both educational levels there is a predominance of the treatment of the concept of density, with the timid appearance of proposals focused on the concept of forces. This appears to be idiosyncratic of the topic of floating and sinking, which at school level seems to be associated with the concept of density in spite of the limitation of this conceptual framework (Viennot, 2014, 2019). This quasi-uniformity of conceptual treatment, we believe for reasons of conceptual survival, can hinder the appearance of other more innovative treatments of modelling by forces. Furthermore, this assumes that the idea of learning progression would be linked solely and exclusively to the concept of density, gradually sophisticating the ideas related to this concept, and leaving aside the one related to the concept of forces, despite its greater explanatory power.

The phenomena selected for working with this topic also show total consensus, as all of the studies found propose the same phenomena, floating and sinking of objects in water and, sometimes, its comparison with other liquids (oil). Again, this uniformity may hinder the appearance of alternative proposals for explaining experiences that are also everyday such as the floating and sinking of objects in gases: smoke as solids in suspension or clouds (solids and liquids in suspension; Lega et al., 2002).

Despite there being general consensus on the phenomena to be worked with, the teaching proposals put forward the use of a multitude of daily testing objects. Therefore, we could argue that the research papers do not give preference to any specific testing object, even those that are designed ad hoc for the classroom. The fact that many testing objects are used for the same situation (objects in water) indicates that there is still no consensus as to which specific paradigmatic phenomenon we should use to learn the concepts regarding floating and sinking.

The papers analysed show a multitude of teaching approaches proposed by the authors (POE, inquiry, modelling, direct instruction experiment, etc.), an example of the historical development of SE itself. Because of the already described delay in research on younger students and due to their different characteristics, the teaching approaches show variations between the proposals for Primary and Secondary Education: in the former there is a predominance of inquiry and in the case of the latter, direct instruction experiment is more widespread, furthermore reinforcing the fact that it is because of the older studies, because of the curricular pressure at this level, as we have commented in previous paragraphs. We believe it important, however, to point out that these differences regarding the teaching approach appear to diminish over the last decade and that by not being in connection with what to teach, they lack potential they could have.

In a similar manner to the historical development of the approaches, the implementation and evaluation of the teaching proposals seems to have been strongly influenced by the historical development undergone by SE research itself. Although in the initial decades there was a focus on considering teaching proposals (without evaluating their effectiveness), the passing of the years meant that this was not enough, thus causing the situation where as well as putting forward teaching proposals, it would have to be demonstrated whether they worked or not.

In summary, and responding to the question we asked in the introduction (Will teachers find consensus on what to teach, on what the prototypical phenomena are, or on what the most appropriate teaching approaches are?) we consider that there are certain aspects in which there is consensus, for example, the most important alternative conceptions have been identified, the phenomenon with which to deal with floating and sinking is common, and content, but there are also dissents, with teaching approaches and testing objects particularly standing out. This situation, therefore, puts us on track for future studies to carry out as regards the phenomena of floating and sinking.

4.6. Contribution to the field

In this paper we have made a systematic literature review of the topic floating and sinking. In our view, the realization of this type of studies, where critical and systematic analysis are made regarding what has been researched so far concerning a given topic, is a pressing need for the proper development of an area of knowledge. Although, indeed, systematic literature reviews are usually carried out at the beginning of doctoral theses, it is also true that they are generally left in a drawer with the 'excuse' that they have been carried out only for the student to 'keep up to date' without the recognition of the greater benefit to all of researchers. Therefore, we would like to kindly encourage the rest of the research community to undertake similar studies concerning other science topics. Likewise, and in response to the urgent need to provide useful and relevant information for teachers, we believe that studies such as the one presented here will be very helpful since they facilitate the connection between the evidence found in scientific literature and classroom practice.

In the case we are dealing with here, research carried out in the area of SE on the phenomena of floating and sinking, we find positive aspects, but also others that should be improved. We find, for instance, that, because there has been some international coherence in the research objectives on the phenomena of floating and sinking, there is an abundance of research that seeks to find out what students' alternative conceptions are and, therefore, we could say that teachers will find a lot of information about it. However, it is important to note that, although there is a critical mass of papers devoted to searching for alternative conceptions, they are presented in a disjointed manner. Therefore, it would be necessary to develop a theoretical and empirical learning progression that specifies the milestones to be reached by the students in order to learn the concept or concepts to be worked on. In other words, we are not guaranteed continuity between educational levels (Primary and Secondary Education)

If we focus on concepts, teachers will find that the scientific literature considers density to be the most appropriate. From our point of view, and without wishing to delegitimise other researchers, this would mean losing the opportunity to provide students with the basic tools to be able to explain the phenomena of floating and sinking. Although different studies claim that density is a simpler concept than forces, due to its descriptive nature, we must bear in mind that it is an inverse relationship, which makes it more complex for younger students. Moreover, according to multiple international reports (European Commision, 2015; NGSS Lead States, 2013), SE should promote students the big ideas of science (Harlen, 2015), in this case the concepts of forces, through key scientific practices (such as inquiry, modelling, argumentation, etc.)

Likewise, we consider positive both the evolution shown by the scientific literature in terms of teaching approaches, betting in recent decades on more socio-constructivist approaches (such as inquiry), and the presentation of teaching proposals in order to evolve the students' ideas. The shortage of TLSs tested show us the need to increase research about evaluation of TLSs , so that we can know with certainty which of them are successful and, therefore, respond to one of the main needs of teachers.

In summary, we could say that of the aspects studied here (such as concepts, context, testing objects, etc.), and bearing in mind what we provide from the scientific literature to teachers, we could conclude that few of the elements studied here are transferable to the classroom. This would indicate a fundamental outcome of this research: there is not only a 'research to practice gap', but also a 'research to research gap' as we are not able to reach a basic consensus on how to provide teachers with products that are consistent with their needs.

The lack of consensus in the research of the phenomena of floating and sinking could also indicate a certain maturity in our field. The main problem lies in the absence of transparency in relation to why we make some decisions or others, like the use of density as the central concept: what are the reasons that authors have chosen it? We need more transparency on this design tool in order to calibrate why it is better density than the forces approximation.

Finally, we would like to introduce a question whose answer we believe should be addressed and reflected upon from the SE area: what is the reason that leads us to use the phenomena of floating and sinking? Are the phenomena of floating and sinking an 'easy context' or a 'paradigmatic phenomena'? These questions are decisive because they will determine what and how we will deal with the phenomena of floating and sinking. According to what has been observed in this study, the phenomena in question seems to be the 'excuse' or the 'pretext' (Marchán-Carvajal & Sanmartí, 2015; Moraga et al., 2019) to work on different skills, better understand the context, etc. However, the phenomena can also be understood as the 'context' that allows students to find an explanation coherent with the ideas of science (forces) and, therefore, to be able to look at it through the eyes of a model (model of forces).

5. Estudio 2. Comparación de secuencias de enseñanza y aprendizaje sobre el fenómeno de flotación como fase preliminar de la investigación de diseño

5.1. Introducción

El diseño y/o modificación de secuencias de enseñanza y aprendizaje (SEA), lejos del carácter normativo o prescriptivo que suele concederle la administración educativa, es una tarea de gran relevancia para el quehacer diario de los docentes (Sanmartí, 2000) pues es la herramienta que nos permite planificar e implementar situaciones de enseñanza y aprendizaje referidas a una temática concreta del currículo escolar. Dado que se trata de la herramienta central del día a día de los docentes (Caamaño, 2013), podríamos afirmar que su selección, diseño y/o modificación, con el fin de adaptarlas a nuestro propio alumnado y contexto, es una de las tareas más habituales.

Las principales fuentes de inspiración de los docentes a la hora de diseñar y/o modificar suelen ser las SEAs elaboradas por otros docentes-investigadores, algunas de ellas publicadas en revistas para profesores (Lijnse & Klaassen, 2004) o, como ocurre en la mayoría de los casos, compartidas en los blogs y redes sociales de los propios docentes (Hou et al., 2009; Schwarz & Caduri, 2016). Muchos de estos diseños están fundamentados en la investigación didáctica (Research Based Design o RBD, Leinonen et al., 2008; Mislevy et al., 2017; Quesnel et al., 2018) y tratan de dar respuesta a las abundantes investigaciones sobre concepciones alternativas a partir de diferentes modelos de diseño y reconstrucción educativa (Couso, 2011). El auge de la línea de investigación sobre concepciones alternativas trajo consigo un amplio consenso al respecto (Jiménez-Pérez, 2012). Sin embargo, no vino aparejada de una producción ni tan abundante ni tan consensuada en cuanto a qué conceptos o modelos científicos escolares enseñar-aprender, qué tipo de tareas que fomentar, qué enfoques de enseñanza son los más adecuados para conseguirlo (Lijnse & Klaassen, 2004) o cómo seleccionar, adaptar y/o diseñar estas SEAs.

Pese a la falta de consenso en aspectos tan relevantes como los citados en el párrafo anterior, sí que hubo una preocupación creciente desde la Didáctica de las Ciencias Experimentales (DCE) por el proceso de diseño o adaptación de SEAs. De hecho, de acuerdo con Méheut & Psillos (2004) y Psillos & Kariotoglou (2016a), desde la década de los 80 surgieron múltiples investigaciones en las que se ha tratado de abordar cómo se diseña una SEA (Andersson & Bach, 2005; Artigue, 1988; Buty et al., 2004; Duit et al., 2005; Leach & Scott, 2002; Lijnse, 1995; Plomp & Nieveen, 2013), qué elementos se utilizan y cómo se pueden operativizar y compartir con otros docentes-investigadores. Surge así la conocida línea de investigación *Design Based Research* o DBR (investigación de diseño o IBD en español), que incluye y amplía al anterior diseño de secuencias fundamentadas en la investigación (RBD), y que se caracteriza por poner el foco no solo en la propia SEA, sino también en paliar las dificultades de los diseñadores a la hora de compartir los fundamentos que sustentan sus diseños: los *design principles o* principios de diseño (Plomp & Nieveen, 2013). Estos principios de diseño, de acuerdo con Nieveen & Folmer (2013), proporcionan información relevante para diseñar SEAs o, dicho con otras palabras, pueden ser considerados como las *guidelines for designing the intervention* (p. 153). Así, y pese a ser el sustento del diseño, los diseñadores de las SEAs no suelen explicitar sus principios de diseño (Guisasola & Oliva, 2020; Méheut & Psillos, 2004; Psillos & Kariotoglou, 2016a), lo que podría llevar a interpretaciones que pueden o no coincidir con las intenciones iniciales de los autores. Cuando son explicitados, por otra parte, suelen ser muy generales y, por tanto, *they are difficult to put into practice, precisely because it does not say very much about how to teach* (Lijnse, 1995; p. 191).

A pesar de la falta de transparencia a la hora de mostrar estos fundamentos de diseño, muchos docentes seguimos inspirándonos en actividades concretas o SEAs de otros docentes-investigadores. Es por ello que en este artículo queremos incorporar esta práctica habitual previa al diseño al marco teórico de la investigación de diseño y, más concretamente, a su fase preliminar. De esta forma, proponemos la comparativa de SEAs como un proceso complementario a las ya típicas revisiones de la literatura sobre concepciones alternativas (Gilbert & Watts, 1983; Hull et al., 2021) o sobre los enfoques de enseñanza (Aguilera Morales et al., 2018; Wright & Park, 2022), además de los estudios comparativos de libros de texto (Ma et al., 2021), de enfoques de enseñanza (Vorholzer et al., 2020) o de currículos educativos (Havu-Nuutinen et al., 2021).

Este estudio, por tanto, viene a cubrir la brecha que existe en la literatura científica en cuanto al uso de la comparativa de SEAs como proceso previo a la selección, adaptación y/o diseño, reconociendo su importancia y apreciando el auténtico valor que aporta al diseño final de una SEA fundamentada en investigación educativa. Para ello, proponemos una comparación de SEAs sobre un contenido en concreto vinculado a la comprensión del fenómeno de flotación y hundimiento de objetos.

Aprovechamos que en el Estudio 1 de la presente Tesis Doctoral realizamos una revisión sistemática de la literatura científica sobre este tópico en la que agrupamos los resultados en torno a una serie de variables (las concepciones alternativas, los conceptos a enseñar-aprender, los *testing objects*, los enfoques de enseñanza, etc.), que nos volverán a ser de utilidad para plantear los resultados de este Estudio 2. De esta forma, queremos responder a las siguientes preguntas de investigación:

- ¿Qué características presentan las SEAs disponibles sobre el fenómeno de flotación y hundimiento de objetos?
- ¿Cómo contribuye a la fase preliminar del diseño esta comparación de SEAs fundamentadas en la investigación (Research Based Design)?
- En relación a la toma de datos, ¿podría ser posible un tratamiento sencillo de los datos que permita la comparación de SEAs sobre un tema científico?

A continuación, hacemos un repaso histórico de las principales teorías de diseño para aclarar qué fases de diseño se proponen desde la literatura y detectar si en alguna han considerado previamente la comparativa de SEAs como parte previa al diseño.

5.2. Antecedentes

La preocupación por realizar investigaciones en contextos específicos con el fin de aportar conocimiento a los procesos de enseñanza y aprendizaje comenzó su andadura hace más de un siglo, cuando John Dewey explicitó la necesidad de tener en cuenta los contextos y sus peculiaridades para la investigación educativa (Guisasola, Ametller, et al., 2021). Con el paso de los años, esta preocupación se ha concretado en toda una línea de investigación que trata de responder a una gran problemática: superar la brecha entre la investigación didáctica y el aula planteando estudios que tengan como origen las problemáticas reales de los docentes y/o alumnos (P. E. M. Romero-Ariza, 2014), de manera que se mejoren los procesos de enseñanza y aprendizaje. Dentro de esta línea de investigación, especial relevancia ha supuesto el diseño de SEAs, que ha sido el foco de atención de multitud de estudios desde la década de los 80 (Psillos and Kariotoglou, 2016).

Cabría mencionar que no existe un consenso generalizado sobre cuál ha de ser el procedimiento a seguir para el diseño de SEAs (Guisasola, Ametller, et al., 2021) o quién ha de realizarlo (Couso, 2016). De hecho, a poco que escudriñemos la literatura didáctica al respecto, podremos encontrar diferentes teorías del diseño, cada una de ellas con sus especificidades: con origen europeo encontramos a *Ingénierie Didactique* (Artigue, 1988), *Developmental Research* (Lijnse, 1995), *Design Briefs* (Leach and Scott, 2002), *Two Worlds* (Buty et al., 2004), *Educational Reconstruction* (Duit et al., 2005, 2012) o el modelo presentado por Andersson and Bach (2005). Con origen estadounidense destaca el *Design-based Research* o *DBR* (Design-based Research Collective, 2003), aunque esta propuesta va más allá del diseño de SEAs, que se conciben como subproducto del propio contexto de investigación educativa. Estas teorías del diseño no son las únicas que aparecen en la literatura didáctica, pero, como afirman Couso (2013), Guisasola et al. (2021) y Psillos & Kariotoglou, (2016b), son las que más impacto han tenido en nuestra área de conocimiento (DCE).

Así pues, e independientemente de la teoría de la que hablemos, todo proceso de diseño de SEAs está influenciado por la elección de una teoría psicológica del aprendizaje. Por ejemplo, tres de las teorías del diseño tienen una visión constructivista del aprendizaje (Andersson and Bach, 2005; Duit et al., 2005, 2012b; Lijnse, 1995) mientras que las otras cuatro se decantan por la socioconstructivista (Artigue, 1988; Buty et al., 2004; Guisasola et al., 2021; Leach and Scott, 2002). De acuerdo con Psillos and Kariotoglou (2016), las teorías de aprendizaje *have not much to offer, however, in designing teaching on a specific topic or providing answers to questions such as "how to deal with students' conceptual difficulties in explaining situation X" or "how to prompt them to relate scientific knowledge to evidence during experimentation in topic Y"* (p.13).

Se empieza a vislumbrar, por tanto, la necesidad de operativizar el proceso de diseño especificando, por un lado, cuáles son las fases imprescindibles para diseñar SEAs y, por otro lado, concretando esas grandes recomendaciones o consensos (principios de diseño) que surgen como consecuencia de las teorías psicológicas del aprendizaje (Buty et al., 2004). En otras palabras, con el paso de los años los estudios relativos al diseño de SEAs han ido evolucionando hacia el planteamiento de un conocimiento mucho más operativo (*usable knowledge* en palabras de The Design-based Research Collective, 2003) que permite salvar la brecha entre el diseño de SEAs y las recomendaciones de las grandes teorías psicológicas del aprendizaje (Plomp, 2013). Se abren paso las *humble theories* (The Design-Based Research Collective, 2003)

En cuanto a las fases de diseño de SEAs, cabe mencionar que cada una de las teorías que hemos considerado presenta matices y aspectos diferenciadores. Esas diferencias se ven reflejadas en el despliegue de multitud de términos para nombrar las fases de diseño, que cuales pueden ser categorizadas en: 1) fases previas al diseño de la SEA; 2) dedicadas al diseño de la SEA; y 3) dedicadas a su implementación y evaluación.

En la primera de las fases, se plantean dos grandes tareas: por un lado, estudiar la literatura científica sobre el concepto que se aborda en la SEA (por ejemplo, analizando cuáles son las concepciones alternativas al respecto) o las formas en las que se ha enseñado (Duit et al., 2005; Guisasola, Ametller, et al., 2021) y, por otro lado, clarificar conceptualmente el contenido a enseñar (Artigue, 1988; Couso, 2013; Couso & Adúriz-Bravo, 2016; Duit et al., 2005; Lijnse, 1995).

En la segunda fase, momento en el que se diseña la SEA, los investigadores presentan los *design principles* que sustentan el diseño, los cuales pueden ser de corte conceptual (*map of concepts* de Andersson & Bach, 2005), epistemológico (Artigue, 1988), de corte psicológico (*learning demand* de Leach & Scott, 2002) o, incluso, emocional (Lijnse, 1995).

En la tercera y última fase, dedicada a la implementación y evaluación de la SEA, las teorías de diseño suelen profundizar menos, aunque todas destacan la necesidad y utilidad de evaluar y mejorar la SEA (Andersson & Bach, 2005; Guisasola, Ametller, et al., 2021; Hernández Rodríguez, 2018)

En estos antecedentes hemos encontrado que ninguna de las teorías de diseño plantea la comparativa de SEAs como una fase previa al diseño. Es por ello que, a través de este estudio, queremos destacar su importancia, así como adentrarnos en una metodología de comparación que pueda ser usada tanto por docentes como investigadores y que aporte información útil para la selección, adaptación y diseño de SEAs.

5.3. Metodología

Como no conocemos antecedentes en los que se comparen SEAs, nos hemos inspirado en la Educación Comparada (Caballero et al., 2016), que hace referencia al estudio de fenómenos o hechos educativos de diferentes lugares del mundo o momentos históricos (p. 41) con el objetivo de aumentar el conocimiento y la comprensión de los mismos (p. 45). A fin de producir descripciones ricas y amplias de los fenómenos o hechos educativos, en este caso las SEAs sobre flotación, implementamos un análisis documental (Bowen, 2009).

El punto inicial de nuestro estudio supone la selección de las SEAs según los siguientes criterios: en primer lugar, que el fenómeno de flotación sea el tema central; en segundo lugar, que las SEAs en cuestión utilicen la indagación y la modelización como enfoques de enseñanza dada su importancia para el desarrollo de la competencia científica (Couso, 2013); y, en tercer lugar, que las SEAs tengan reconocimiento en el ámbito académico – ya sea porque hayan sido presentadas en tesis doctorales, proyectos de investigación nacionales o internacionales o artículos de investigación – pues asumimos que, al estar publicadas, han pasado por procesos de evaluación.

Teniendo en cuenta estos criterios, disponemos de cinco SEAs a comparar: 1) *Ni flota ni se hunde* (Vokos et al., 2021; pp. 4-5); 2) *¿Por qué flotan algunas cosas?* (Garrido Espeja, 2016); 3) *Exploring flotation of objects in liquids* (Rodrigues et al., 2021); 4) *Density of materials in floating/sinking phenomena* (Zoupidis et al., 2016); y 5) *Sink or Float* (Harlen & Léna, 2010). Es importante señalar que no hemos utilizado como criterio excluyente el nivel educativo al que van dirigido, pues las dos primeras están diseñadas para trabajar en formación inicial de maestros (y, por tanto, requieren de adaptación para su aplicación con niños de 6-12 años) mientras que las otras tres han sido diseñadas para su aplicación directa en los niveles educativos de Primaria y primeros cursos de Secundaria.

Una vez seleccionadas, pasamos a la identificación de las variables a analizar en las cinco SEAs. Para ello, nos inspiramos en dos recursos: por un lado, en el protocolo de análisis realizado en el Estudio 1 de la presente Tesis Doctoral (Annex II), que presenta las siguientes variables: 1) los objetivos de investigación propuestos desde los artículos; 2) los conceptos seleccionados para abordar el fenómeno en cuestión; 3) el enfoque de enseñanza planteado; 5) la evaluación de las propuestas; y 6) nivel educativo en el que se centran los artículos. Por otro lado, en la *German didaktik tradition* (Heinmann et al., 1969), desde la cual se considera que, para el diseño de SEAs, hay que valorar: 1) intentions (aims and objectives); 2) topic of instruction (content); 3) methods of instruction; 4) media used in instruction.

De todas esas variables, para la comparación de las cinco SEAs sobre flotación y hundimiento de objetos, nos son útiles las siguientes:

- Concepciones alternativas que tratan de abordar las SEAs.
- El tratamiento conceptual de las SEAs para explicar el fenómeno de flotación y hundimiento de objetos.
- Los tipos de *testing objects* empleados en cada una de las SEAs.
- El número de *testing objects* usados.
- El número de tareas que componen las SEAs.
- El enfoque de enseñanza elegido por los autores de las SEAs.

Sería interesante introducir la variable *evaluación de la propuesta,* de forma que seamos conscientes de si la SEA ha sido pilotada y evaluada. No obstante, la dificultad para encontrar las SEAs completas y la no disponibilidad de le evaluación de las mismas, nos ha llevado a no incorporarla entre las variables aquí definidas.

Tras identificar estas variables, hemos determinado cuáles son las categorías que incluimos dentro de ellas. Por ejemplo, dentro de la variable tipo de *testing objects* hemos planteado tres categorías: una donde indicamos si el *testing object* es cotidiano o específicamente diseñado para abordar la enseñanza y el aprendizaje de la flotación; otra en la que señalamos el *testing object* concreto que se está utilizando; y finalmente una en la que identificamos si el *testing object* es real o simulado. En el Annex III mostramos toda la información sobre el resto de categorías para cada variable. Para evaluar la validez y fiabilidad de estas variables, han sido aplicadas por dos de los tres autores, de forma independiente, con un porcentaje de acuerdo superior al 85%. Con el fin de superar los disensos, realizamos múltiples reuniones y redefinimos algunas de las variables para, de esta forma, llegar a la propuesta consensuada que presentamos.

Una vez categorizadas las cinco SEAs en base a lo dispuesto en el Annex III, procedemos a un segundo nivel de categorización. En él, inspirándonos en la idea de rúbricas para la investigación (Dawson, 2015; Pérez-Torres et al., 2021), establecemos cuatro niveles de sofisticación para cada una de las variables previamente identificadas (concepciones alternativas, tratamiento conceptual, *testing objects*, número de tareas y enfoque de enseñanza). Aquí es importante destacar dos aspectos: por un lado, que nuestro objetivo no es ni generalizar ni valorar negativamente ninguna de las SEAs, sino la comparación de sus características particulares y, por otro lado, que los niveles de sofisticación han sido obtenidos de forma emergente, a partir de los datos (Figure 34). Las definiciones de los niveles de sofisticación pueden ser encontradas en la Table 3.

Así, la lógica que sigue la doble categorización que aquí presentamos, y siguiendo con el ejemplo anterior, es la siguiente: en primer lugar, identificamos el tipo de *testing object* que se está utilizando en la SEA: *daily testing object* o *classroom testing object*; en segundo lugar, especificamos cuál es el *testing object*; en tercer lugar, establecemos si es real o simulado; y, en cuarto lugar, en base a los niveles de sofisticación definidos, determinamos en qué nivel se encuentra la SEA. A continuación, mostramos un ejemplo de categorización con la SEA presentada por la Universidad de Almería: 1) tipo de *testing object*: *classroom testing object*; 2) *testing object* usado: bote de cristal hermético; 3) real o simulado: el bote de cristal es real; 4) nivel de sofisticación tres: es un *classroom testing object* específicamente elegido por el docente.

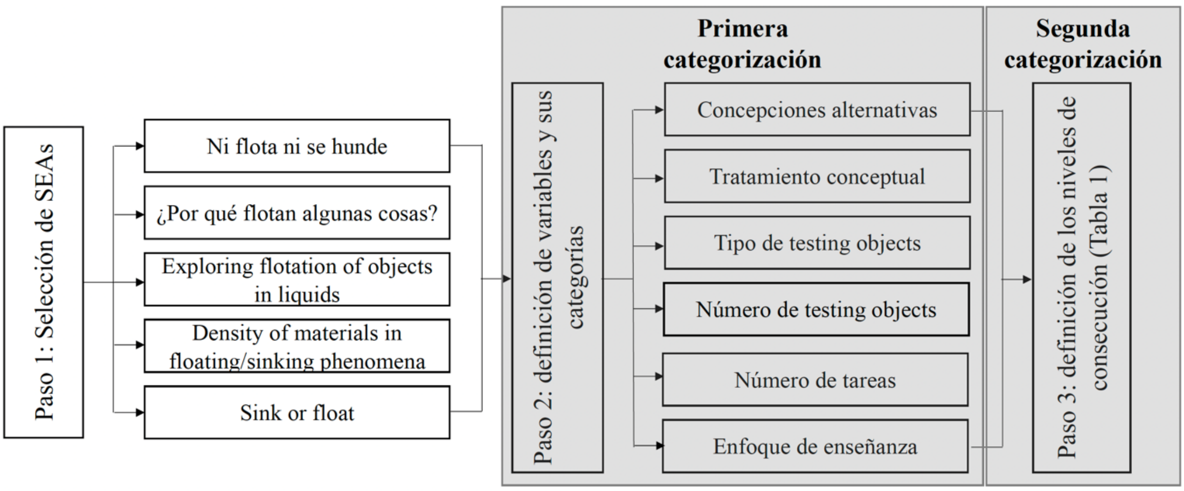


Figure 34. Proceso implementado para la categorización de las SEAs

Una vez que cada SEA ha sido analizada en función de las variables previamente indicadas mediante el software cualitativo ATLAS.TI (versión 9), representamos gráficos radiales con el software EXCEL (versión 16.61). Ello nos permite obtener pantallazos de cada una de las SEAs, facilitando, por un lado, la visualización rápida de sus características y, por otro lado, la comparativa con el resto de ellas (Figure 35).

Table 3. Niveles de sofisticación en relación a las variables de estudio

Variables	Niveles de sofisticación
Concepciones alternativas sobre densidad	Nivel 0. Aquellas SEAs que ponen en conflicto las concepciones alternativas sobre masa, peso, volumen y capacidad.
	Nivel 1. Aquellas SEAs que ponen en conflicto las concepciones alternativas sobre la densidad (m/v).
	Nivel 2. Aquellas SEAs que ponen en conflicto las concepciones alternativas sobre la densidad relativa.
	Nivel 3. Aquellas SEAs que ponen en conflicto las situaciones en las que los objetos flotan/se hunden en función de la densidad relativa.
Concepciones alternativas sobre fuerzas	Nivel 0. Aquellas SEAs que ponen en conflicto las concepciones alternativas sobre fuerza peso/empuje
	Nivel 1. Aquellas SEAs que ponen en conflicto las concepciones alternativas sobre situaciones estáticas en la interacción de fuerzas.
	Nivel 2. Aquellas SEAs que ponen en conflicto las concepciones alternativas sobre situaciones estáticas en la interacción de fuerzas.
	Nivel 3. Aquellas SEAs que ponen en conflicto las concepciones alternativas sobre situaciones dinámicas en la interacción de fuerzas
Tratamiento conceptual	Nivel 0. Aquellas SEAs que abordan el concepto de densidad o fuerzas de forma errónea
	Nivel 1. Aquellas SEAs que abordan la flotación desde la densidad.
	Nivel 2. Aquellas SEAs que abordan la flotación desde las fuerzas.
	Nivel 3. Aquellas SEAs que reconcilian las fuerzas con la densidad.
Tipo de *testing objects*	Nivel 0. Aquellas SEAs que no utilizan objetos ni reales ni simulados
	Nivel 1. Aquellas SEAs que utilizan *daily testing objects* elegidos por el alumnado.
	Nivel 2. Aquellas SEAs que utilizan *daily testing objects* elegidos por el docente
	Nivel 3. Aquellas SEAs que utilizan *classroom testing objects* elegidos por el docente
Número de *testing objects*	Nivel 0. Aquellas SEAs que no presentan ningún *testing object* o son una simulación digital
	Nivel 1. Aquellas SEAs que presentan entre 1-5 *testing objects*
	Nivel 2. Aquellas SEAs que presentan entre 5-10 *testing objects*
	Nivel 3. Aquellas SEAs que presentan más de 10 *testing objects*
Número de tareas	Nivel 0. Aquellas SEAs que presentan entre 0-5 tareas.
	Nivel 1. Aquellas SEAs que presentan entre 6-11 tareas.
	Nivel 2. Aquellas SEAs que presentan entre 12-17 tareas.
	Nivel 3. Aquellas SEAs que presentan más de 18 tareas.
Enfoque de enseñanza	Nivel 0. Aquellas SEAs que no especifican el enfoque de enseñanza que utilizan.
	Nivel 1. Aquellas SEAs que utilizan como enfoque de enseñanza: a) indagación no dirigida a la construcción de modelos sino a evidenciar la relación entre conceptos o b) una modelización en la que no se construye el modelo, sino que se explica por parte del docente.
	Nivel 2. Aquellas SEAs que utilizan como enfoque de enseñanza: a) indagación dirigida a la construcción de modelos o b) una modelización en la que se construye el modelo de forma guiada.
	Nivel 3. Aquellas SEAs que utilizan como enfoque de enseñanza *Model-based Inquiry* (MBI): uso de la indagación y modelización en una misma SEA con el fin de construir un modelo.

5.4. Resultados

Para obtener una visión amplia y clara de cuáles son las principales características de las cinco SEAs comparadas, mostramos los resultados a través de dos *zooms*: en el primero planteamos una visión más general de los resultados mediante la descripción de las gráficas radiales surgidas como consecuencia de la categorización previamente descrita. En el segundo *zoom* mostramos las tareas más singulares de cada una de las SEAs.

5.4.1. Descripción comparada de las cinco SEAs

Con el objetivo de destacar las principales características de cada una de las cinco SEAs sobre flotación y hundimiento de objetos, mostramos los gráficos radiales de la Figure 35. Las variables que aparecen en dichos gráficos son (de arriba hacia la derecha): concepciones alternativas tratadas sobre densidad (1) o fuerzas (2); tratamiento conceptual por densidad o fuerzas (3); tipo de *testing objects* (*daily* o *classroom*), 4); número de *testing objects* (5); número de tareas (6) y enfoque de enseñanza (7). De esta forma, e inspirados en la propuesta de Pérez-Torres et al. (2021), quedan representadas dos grandes zonas en el gráfico: la parte derecha corresponde a los aspectos conceptuales de las SEAs, mientras que la de la izquierda muestra los aspectos didácticos.

En la Figure 35, las tres gráficas superiores (*Sink or float*, *Exploring flotation of objects in liquids* y *Density of materials in floating/sinking phenomena*), son similares porque encaran el fenómeno de flotación de acuerdo con el concepto de densidad y, por tanto, abordan solo esas dificultades o concepciones alternativas de los estudiantes, dejando vacía las correspondientes a fuerzas. Por el contrario, las dos SEAs restantes (*¿Por qué flotan algunas cosas?* y *Ni flota ni se hunde*), abordan el fenómeno de flotación a través de fuerzas y, además, reconcilian este tratamiento conceptual con el de densidad a pesar de que no tratan específicamente ninguna concepción alternativa sobre densidad. Las diferencias entre ambos tratamientos conceptuales de las cinco SEAs se muestran claramente en la zona didáctica de las gráficas radiales (margen izquierda).

Dos de las SEAs que abordan la flotación mediante el tratamiento conceptual por densidad (*Sink or float* y *Exploring flotation of objects in liquids*) muestran un gráfico prácticamente idéntico. Ambas usan el enfoque de enseñanza por indagación sin intención modelizadora, conceptualizando y operativizando el concepto de densidad y poniendo en conflicto sus concepciones alternativas. Como no plantean un proceso de construcción de modelos en relación a la densidad, los alumnos construyen un tipo de conocimiento local que les permitirá usar dicho concepto, pero no explicarlo y/o justificarlo. La tercera SEA con tratamiento conceptual por densidad, *Density of materials in floating/sinking phenomena,* emplea el enfoque de enseñanza por modelización con el fin de construir con su alumnado un modelo que permita comprender por qué se produce la densidad: *modelo por puntos* o *dots model*.

Asimismo, estas tres SEAs por densidad coinciden en el elevado número de *testing objects* empleados, destacando la SEA *Exploring flotation of objects in liquids* (con 74), seguida de *Density of materials in floating/sinking phenomena* (con 27) y, finalmente, *Sink or float* (con 22). Las principales diferencias que presentan en relación a los *testing objects* es que *Sink or float* utiliza objetos de la vida cotidiana elegidos *ex profeso; Exploring flotation of objects in liquid* emplea mayoritariamente objetos específicamente diseñados para abordar la flotación, aunque algunos (una cifra mucho menor) eran también cotidianos; y, en el caso de *Density of materials in floating/sinking phenomena,* optan por objetos específicamente diseñados pero, a diferencia del resto de SEAs, son simulaciones por ordenador diseñadas *ad hoc*, lo que, desde nuestro punto de vista, puede ser positivo al no necesitar de materiales reales (a veces de difícil acceso para los docentes) para abordar los diferentes aspectos relativos a la densidad.

Las SEAs *¿Por qué flotan algunas cosas?* y *Ni flota ni se hunde* optan por un tratamiento conceptual por fuerzas y, en ambos casos, tratan de construir un modelo que les permita no solo describir sino también explicar y predecir el fenómeno de la flotación. En otras palabras, podríamos afirmar que ambas SEAs tienen como objetivo que sus alumnos sean capaces de explicar y justificar el mecanismo que provoca que los objetos floten o se hundan. Para ello, la SEA *¿Por qué flotan algunas cosas?* utiliza el enfoque de enseñanza por modelización con especial énfasis, a diferencia de lo que ocurría en la SEA *Density of materials in floating/sinking phenomena,* en la construcción junto con su alumnado del modelo. Esto es, no se trataría de presentarle al alumnado el modelo, sino que ellos mismos lo construyan de forma guiada. En cuanto a la SEA *Ni flota ni se hunde* emplea el enfoque *Model-based Inquiry*, construyendo junto con su alumnado, en primer lugar, un conocimiento más local (para que ni flote ni se hunda el objeto, el peso de dicho objeto ha de ser igual al peso del agua que desaloja) y, en segundo lugar, otro de carácter más interpretativo: el modelo que les permite explicar por qué sucede.

En ambas SEAs el número de *testing objects* es muy reducido (uno por cada SEA) si lo comparamos con la cantidad utilizada por las secuencias con tratamiento conceptual por densidad. La principal diferencia entre ambas es que una (*¿Por qué flotan algunas cosas?*) se decanta por un objeto de la vida cotidiana (un vaso de plástico) elegido *ex profeso* y la otra, *Ni flota ni se hunde,* emplea un objeto específicamente elegido para trabajar en el aula (un bote de cristal transparente con cierre hermético que puede llenarse o vaciarse de diferentes materiales).

Por último, otra diferencia entre las SEAs con tratamiento conceptual por densidad o por fuerzas hace referencia al número de tareas que proponen: mientras que en las SEAs por densidad plantean más de 17 (37 tareas en *Exploring flotation of objects in liquids*; 21 en *Sink or float;* y 17 en *Density of materials in floating/sinking phenomena)*, en las SEAs por fuerzas solo plantean 11 (*Ni flota ni se hunde*) y 10 (*¿Por qué flotan algunas cosas?*). Creemos que esto podría deberse a que las tres SEAs por densidad están diseñadas para la etapa escolar de Educación Primaria, por lo que las tareas suelen tener una menor duración y se dedica más tiempo a la construcción de ideas. En cambio, las SEAs por fuerzas están diseñadas para la formación inicial de maestros, por lo que cada tarea puede tener una mayor duración al ir dirigidas a adultos.

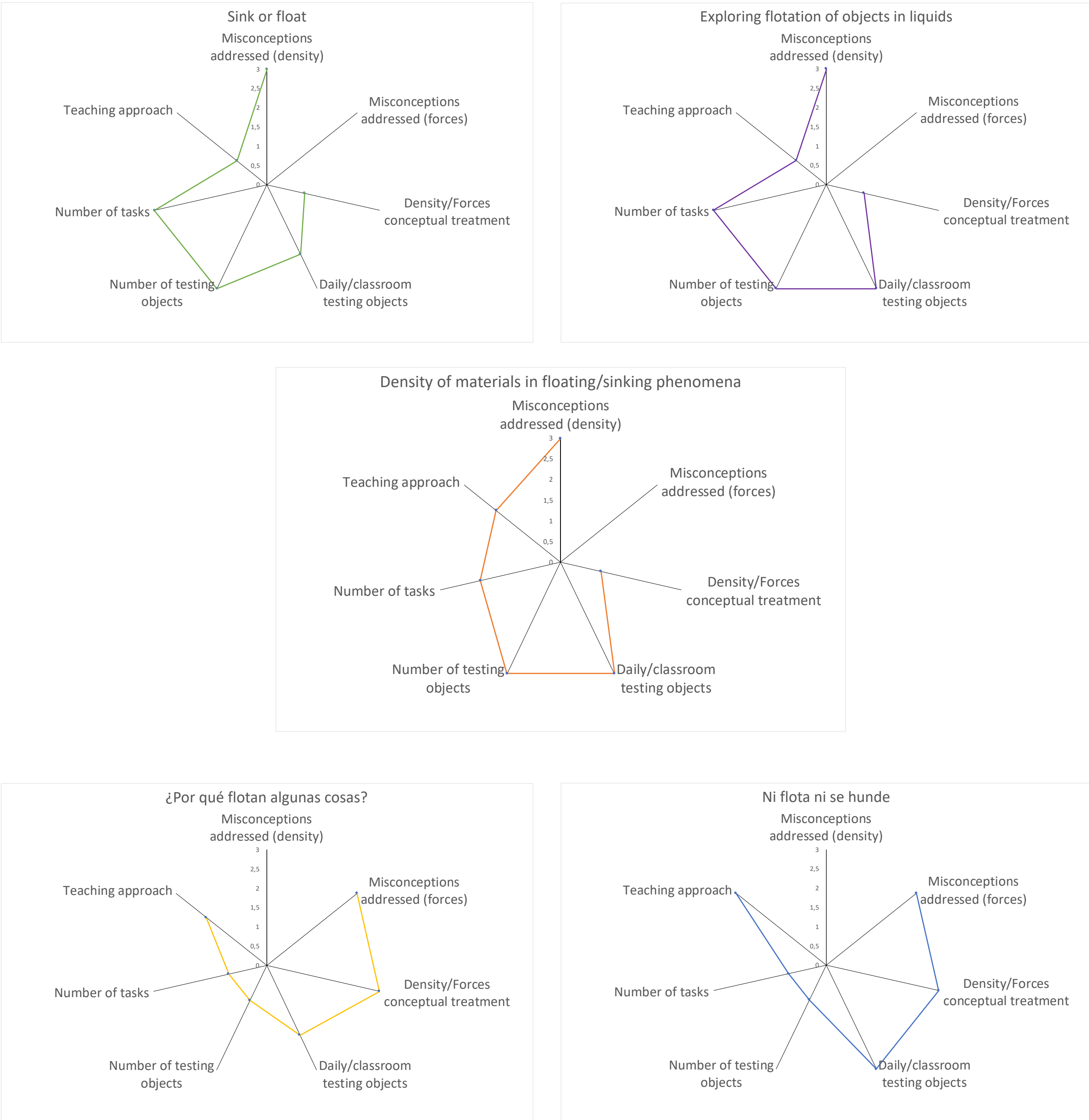


Figure 35. Gráficos radiales de las SEAs sobre flotación y hundimiento de objetos

5.4.2. Actividades singulares en cada SEA

Como hemos indicado en la introducción, uno de los objetivos principales a la hora de aproximarnos a las SEAs diseñadas por otros, así como a su comparativa, es inspirarnos a partir de las tareas que proponen, su estructura, etc. Teniendo esto en cuenta, queremos completar la información aportada en los párrafos anteriores con ejemplos de tareas singulares de cada una de las SEAs.

Las SEAs que abordan la flotación por densidad plantean tareas muy similares, en tanto en cuanto las tres usan el control de variables y la comparación de densidades (densidad relativa) como elementos estructurales de sus SEAs. Un ejemplo de tarea paradigmática en las tres SEAs es aquella en la que se pone en conflicto la idea de que la cantidad de líquido (agua en este caso) afecta a la flotabilidad de los objetos. En la Figure 36 mostramos un extracto de dos de las tres SEAs donde se aborda esta concepción alternativa[2].

2.1 DOES THE WIDTH OF A VESSEL AFFECT FLOATING?

SOFTWARE: Room "Testing width of containers"
We have a narrow and a wide vessel filled with water. We have a piece of wood.

SEA: Density of materials in floating/sinking phenomena

Sequence 5: How the Amount of Water Influences Floatability

The amount of water does not have any influence on the floatability of an object (1 session).
Objective: Observe the influence of the amount of water on an object's floatability.

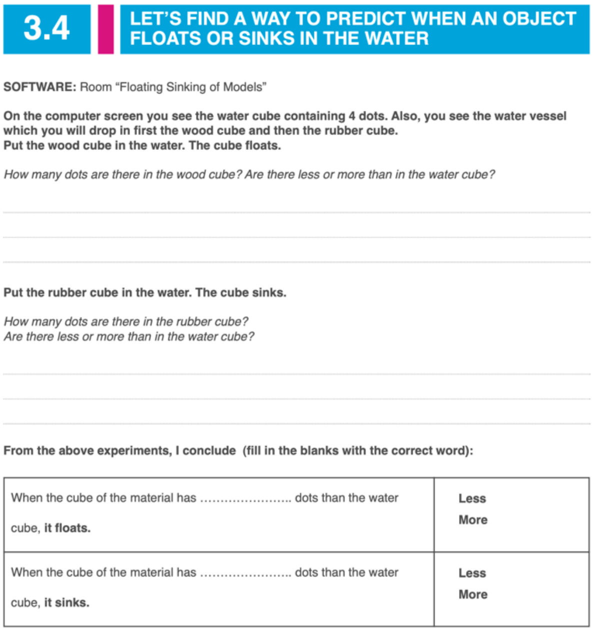
SEA: Sink or float

Figure 36. Tareas que abordan la concepción alternativa de que la cantidad de agua afecta a la flotación (Harlen & Léna, 2010; Zoupidis et al., 2016)

Así pues, y aunque muestren muchas similitudes entre las tres, también aparecen tareas singulares y únicas que no aparecen en las otras. Dada la importancia y la riqueza que supone el compartir tareas diseñadas por otros, hemos considerado relevante destacar algunas de estas tareas singulares ante el resto de la comunidad educativa. Por ejemplo, en la SEA *Density of materials in floating/sinking phenomena* plantean lo que denominan como el *modelo de puntos* o *crowdedness model* para predecir qué objetos flotarán y cuáles se hundirán. De acuerdo con el *modelo de puntos*, si un objeto

[2] En el caso de la SEA *Exploring flotation of objects in liquids* no mostramos directamente las tareas por deseo expreso de sus autores. En lugar de ello, describimos qué es lo que se propone en cada una de ellas. Para contactar con los autores ver Annex IV

tiene más puntos que un líquido, se hundirá. Lo contrario sucederá si el líquido tiene más puntos que el objeto (ver Figure 37).



3.4 LET'S FIND A WAY TO PREDICT WHEN AN OBJECT FLOATS OR SINKS IN THE WATER

SOFTWARE: Room "Floating Sinking of Models"

On the computer screen you see the water cube containing 4 dots. Also, you see the water vessel which you will drop in first the wood cube and then the rubber cube.
Put the wood cube in the water. The cube floats.

How many dots are there in the wood cube? Are there less or more than in the water cube?

Put the rubber cube in the water. The cube sinks.

How many dots are there in the rubber cube?
Are there less or more than in the water cube?

From the above experiments, I conclude (fill in the blanks with the correct word):

When the cube of the material has .... dots than the water cube, **it floats.**	**Less** **More**
When the cube of the material has .... dots than the water cube, **it sinks.**	**Less** **More**

Figure 37. Tarea que aborda la flotación mediante el *modelo de puntos* (Zoupidis et al., 2016)

Por su parte, la secuencia *Sink or float* propone al alumnado construir dos densímetros con una pajita y un trozo de plastilina, de manera que lleguen a la conclusión de que un objeto puede flotar/hundirse más fácilmente dependiendo de la densidad relativa (Figure 38).

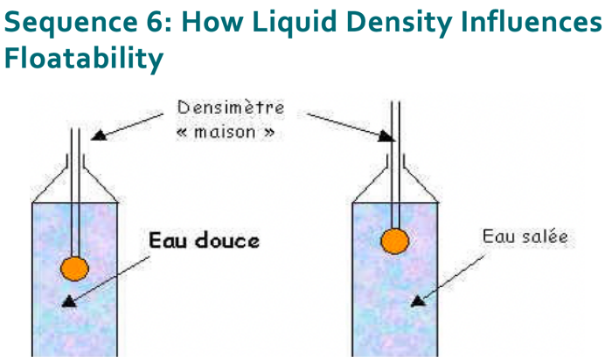


Figure 38. Tarea que aborda la densidad relativa mediante la construcción casera de dos densímetros (Harlen & Léna, 2010)

La SEA *Exploring flotation of objects in liquids* explora con su alumnado el concepto de *carga límite*, entendiéndose como el peso máximo que puede alcanzar un objeto para que deje de flotar. Para abordar dicho concepto, los autores plantean una tarea en la que el alumnado tiene que incorporar diferentes tipos de objetos a otro que previamente flotaba hasta que se hunda.

En cuanto a las dos SEAs que abordan el fenómeno de flotación mediante fuerzas, encontramos similitudes en cuanto al tratamiento conceptual, pero no tanto en las tareas. No obstante, y al igual que hemos hecho con las tres SEAs sobre densidad, nos gustaría destacar algunas tareas que nos han parecido de gran relevancia e interés para el lector. Así, la SEA *¿Por qué flotan algunos objetos?* plantea una tarea que, desde nuestro punto de vista, es clave para la comprensión del modelo de fuerzas. De acuerdo con la tarea en cuestión, el alumnado tiene que coger un vaso de plástico vacío (lleno de aire) e intentar hundirlo *haciendo un agujero en el agua* (Figure 39), siendo el objetivo de la tarea que el alumnado perciba la *fuerza empuje*.

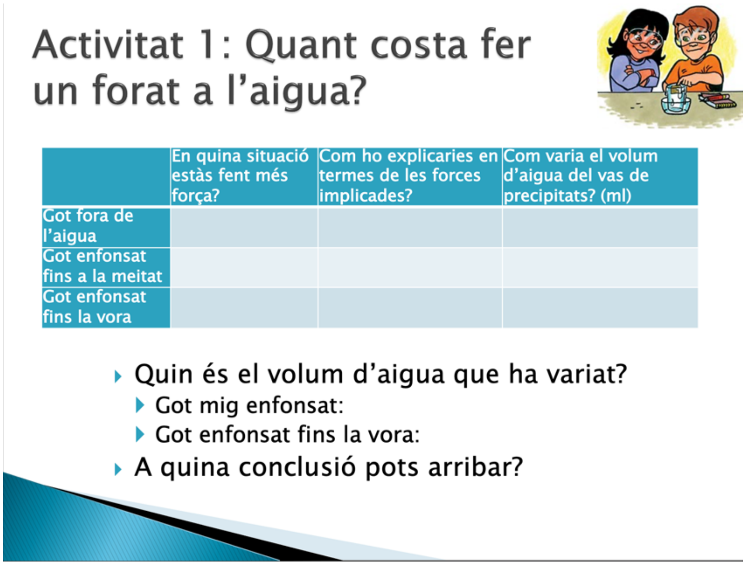


Figure 39. Tarea que aborda la percepción de la fuerza empuje (Garrido Espeja, 2016)

La tarea clave en el caso de la SEA *Ni flota ni se hunde* es la primera, pues marca el resto del diseño. En ella, los alumnos tienen que conseguir que un bote de cristal hermético ni flote ni se hunda, introduciendo, para ello, arena en su interior (Figure 40). Desde nuestro punto de vista, el interés de la tarea reside en que obliga al alumnado a pensar en dos fuerzas desde el comienzo de la SEA al tener que conseguir el equilibrio entre la fuerza peso y la fuerza empuje.

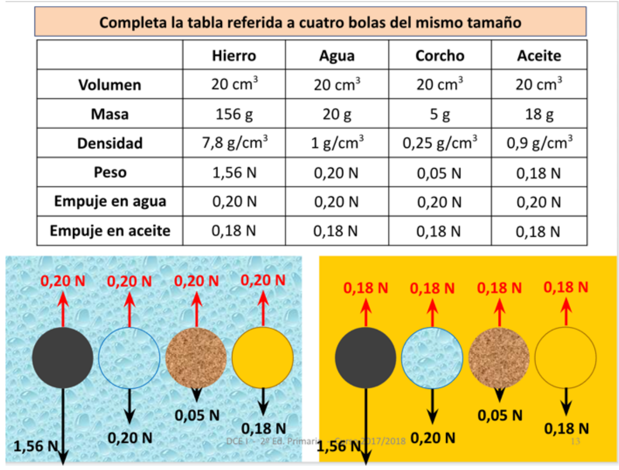
A1. ¿Cuánta arena crees que hay que echar en el bote para que, una vez cerrado, cuando lo dejemos en un recipiente con agua, se quede totalmente cubierto de agua pero sin irse hasta el fondo? *(ni flota ni se hunde, efecto medusa)*

Adelanta una respuesta y diseña un procedimiento para comprobarlo.

¿Y si en lugar de arena fuesen tuercas de hierro, serrín, agua...?

Figure 40. Tarea que aborda el equilibrio de fuerzas (Vokos et al., 2021; pp. 4-5)

Así pues, una de las principales características de estas dos SEAs, que como decíamos están diseñadas para la formación inicial de maestros, es que plantean tareas donde el alumnado ha de reconciliar el uso de las fuerzas y la densidad para explicar la flotación en diversas situaciones (Figure 41).



	Hierro	Agua	Corcho	Aceite
Volumen	20 cm³	20 cm³	20 cm³	20 cm³
Masa	156 g	20 g	5 g	18 g
Densidad	7,8 g/cm³	1 g/cm³	0,25 g/cm³	0,9 g/cm³
Peso	1,56 N	0,20 N	0,05 N	0,18 N
Empuje en agua	0,20 N	0,20 N	0,20 N	0,20 N
Empuje en aceite	0,18 N	0,18 N	0,18 N	0,18 N

Figure 41. Tarea que aborda la reconciliación de los conceptos fuerzas y densidad (Garrido Espeja, 2016; Vokosa., 2021; pp. 4-5)

5.5. Discusión

La comparación de las cinco SEAs aquí mostradas nos permite vislumbrar algunos aspectos clave a la hora de diseñar una SEA sobre flotación y hundimiento de objetos. De acuerdo con los datos que aquí mostramos, existen dos variables que parecen condicionar el diseño de la SEA: por un lado, el tratamiento conceptual y, por otro lado, el enfoque de enseñanza.

Aquellas SEAs que presentan un tratamiento conceptual por densidad, plantean un mayor número de *testing objects* durante toda la secuencia. Creemos que uno de los motivos que ha llevado a los diseñadores a plantear tantos *testing objects* es la necesidad de poner en conflicto muchas concepciones alternativas, como por ejemplo, que la masa o el volumen determinan por sí solos la flotabilidad de los objetos, pero también que la cantidad de líquido o el diámetro de recipiente afecta a dicha flotabilidad. Así, el hecho de poner en conflicto tal número de concepciones alternativas provoca que los diseñadores tengan que seleccionar muy bien los *testing objects* a fin de controlar las variables. Esto podría indicar una relación directa entre SEAs que abordan el fenómeno de flotación mediante la densidad y un número elevado *testing objects,* independientemente de si son reales o simulaciones.

Asimismo, el enfoque de enseñanza también influye en el tipo de tareas planteadas. Aquellas SEAs que abordan la flotación a través de la indagación sin intención de construir un modelo (*Sink or float* y *Exploring flotation of objects in liquids*) plantean únicamente tareas del tipo *hands-on,* donde el resultado será la construcción de un conocimiento local y descriptivo (por ejemplo, el objeto se hunde porque es más denso que…). Sin embargo, la tercera SEA que utiliza la densidad como tratamiento conceptual (*Density of materials in floating/sinking phenomena*), además de plantear tareas tipo *hands-on* (a través de simulaciones informáticas), también diseñan tareas de carácter *minds-on* donde tienen que utilizar un modelo (*dots model* en este caso) para explicar las situaciones relativas a flotación.

Las SEAs que utilizan el tratamiento conceptual por fuerzas plantean un menor numero de *testing objects*. A diferencia de lo que sucede en las SEAs por densidad, cuando se aborda el fenómeno de flotación por fuerzas no se pretende poner en conflicto cada una de las concepciones alternativas, sino más bien construir de manera sencilla los diferentes aspectos del modelo: la existencia de la fuerza peso y empuje; la interacción que se produce entre estas fuerzas y el objeto; y las consecuencias de esa interacción: equilibrio o desequilibrio. De esta forma, parece vislumbrarse que en el tratamiento conceptual por fuerzas hay menos variables a controlar (la fuerza peso y la fuerza empuje), por lo que no es necesario un elevado número de *testing objects* (en ambos casos solo utilizan uno), como así ocurre en las SEAs de densidad.

Al igual que dijimos en párrafos anteriores, el enfoque de enseñanza también ha influenciado en el tipo de tareas que aparecen en ambas SEAs. En el caso de la SEA *Ni flota ni se hunde* plantean, al igual que en *Sink or float* o *Exploring flotation of objects in liquids*, tareas tipo *hands-on*. Sin embargo, tienen una intencionalidad muy diferente: construir el modelo de fuerzas. Por ello, aunque en un primer momento el alumnado adquiere un conocimiento de tipo local (para que ni flote ni se hunda el peso del objeto tiene que ser igual al peso del agua desalojada), acto seguido se plantean tareas que tienen como fin último que el alumnado se plantee el porqué de ello (construcción de modelos). La SEA *¿Por qué flotan algunas cosas?*, por su parte, se focaliza mayoritariamente en tareas tipo *minds-on* (por ejemplo, ¿cómo explicarías…? o ¿por qué crees que pasa…?).

Así pues, si en algo parecen coincidir todas las SEAs es en la importancia de seleccionar cuidadosamente los *testing objects*. Como se puede observar en las gráficas presentadas en la Figure 35, todas las SEAs, independientemente de si se tratan de objetos de la vida cotidiana o específicamente diseñados para el aula, son seleccionados por los docentes/diseñadores. Esto parece contradecir los resultados hallados en el Estudio 1 de la presente Tesis Doctoral, donde el 62% de las SEAs encontradas en la literatura usaban *testing objects* traídos al azar por los estudiantes. Desde nuestro punto de vista, esta selección cuidadosa de los *testing objects* no es ni mucho menos baladí, pues responde a una planificación adecuada de los objetivos de aprendizaje.

A partir de los *testing objects* y las tareas planteadas en las cinco SEAs, podemos extraer cuál ha sido el contexto concreto con el que se ha abordado la flotación. De forma similar a lo hallado en la revisión sistemática del Estudio 1, el contexto por excelencia sigue siendo la flotación de objetos en líquidos, destacando por encima de todo el agua. Por tanto, y pese a que estamos inmersos en un océano de aire en el que vemos diariamente aviones o globos que flotan, la tendencia sigue siendo a utilizar el mismo contexto. Esto podría deberse a que la explicación del fenómeno de flotación en líquidos es más intuitiva para el alumnado. No obstante, y si entendemos a la enseñanza de las ciencias como un proceso continuo de sofisticación de ideas científicas (Couso, 2020), la idea de flotación en otro tipo de fluidos, como los gases, debiera ser tratada.

Por último, también nos gustaría remarcar la riqueza que supone la comparación de SEAs que abordan un mismo fenómeno para los docentes e investigadores. Cuando hablamos de diseñar, la creatividad es un recurso muy valioso, pero también lo es todo lo que se ha hecho con anterioridad. En este sentido, creemos profundamente que no se trataría de "inventar la rueda" continuamente, sino utilizar muchos de los recursos o, en este caso, tareas que previamente han sido desarrolladas con efectividad acreditada. Las tareas que aquí hemos mostrado, así como su comparativa en relación a diferentes variables, son elementos muy valiosos que aportan información al diseño, por lo que, con la operativización de todo este proceso, estaríamos visibilizando un recurso que es útil no solo para los investigadores, sino también los docentes.

5.6. Conclusiones

En esta investigación hemos comparado cinco SEAs sobre el fenómeno de flotación y hundimiento de objetos en torno a las siguientes variables: concepciones alternativas (sobre densidad o fuerzas); tratamiento conceptual; tipo de *testing object*; número de *testing objects*; número de tareas; y enfoque de enseñanza. En cuanto a la primera pregunta de investigación que planteamos en este estudio, de las variables comparadas, dos de ellas parecen ser de gran relevancia por cómo condiciona a la hora de diseñar: el tratamiento conceptual (por densidad o fuerzas) y el enfoque de enseñanza (indagación y/o modelización).

En el caso del tratamiento conceptual, cuando las SEAs están basadas en la densidad, se necesita utilizar un número de *testing objects* más elevado que en las SEAs por fuerzas. Esto es debido a que, mientras que en el primero de los casos se ponen en conflicto un gran número de concepciones alternativas y se han de controlar las variables de forma exhaustiva, en el segundo, no es necesario poner en conflicto tantas ideas sino más bien introducir las ideas clave del modelo (por ejemplo, la interacción de dos fuerzas (peso y empuje)), para lo que se suele requerir solo un objeto a sumergir en agua.

Del mismo modo, observamos que el enfoque de enseñanza influye decisivamente en el diseño de las SEAs y, más concretamente, en el tipo de tareas planteadas. Si se apuesta por el enfoque de enseñanza por indagación sin construcción de modelos, las tareas son exclusivamente del tipo *hands-on,* donde se construye conocimiento local. No obstante, si se encara la flotación a través del enfoque de enseñanza por modelización (o su combinación con la indagación), priman las *minds-on*, donde el fin último es la construcción de un modelo, en combinación con las tareas *hands-on* (para probar el modelo, por ejemplo).

Siguiendo con el tratamiento conceptual, cabe mencionar que ya en el Estudio 1 de esta Tesis Doctoral vislumbramos una asociación entre dicho tratamiento y cursos educativos: mientras que la densidad es asociada a cursos inferiores (Educación Primaria), las fuerzas se reservan a los superiores (Educación Secundaria o formación inicial de maestros). La comparativa de las cinco SEAs parece mostrarnos, por el contrario, que abordar la flotación por densidad requiere controlar muchas más variables (masa, volumen, su relación en forma de división, cantidad de líquido, etc.) que en el caso de las fuerzas (donde únicamente se hace una comparativa entre la fuerza peso y la fuerza empuje). Por tanto, y siguiendo con la idea de Harlen (2010) de que la escuela debe promover la construcción de las grandes ideas de la ciencia, entre ellas las relacionadas con las fuerzas, no debe extrañar que el tratamiento por fuerzas pueda plantearse desde la Educación Primaria.

En lo referente a la segunda pregunta de investigación, si bien la revisión sistemática que realizamos en el Estudio 1 de la presente Tesis Doctoral nos aportó mucha información (por ejemplo, con respecto las concepciones alternativas a abordar cuando se trabaja la flotación), consideramos que dicha revisión, al menos en el caso de flotación y hundimiento de objetos, podría llegar a dificultar el proceso diseño, en tanto en cuanto hay una visible falta de consenso en relación al tratamiento conceptual, el enfoque de enseñanza, o algo tan concreto como los *testing objects* a seleccionar. La comparación de SEAs nos ha permitido clarificar aspectos tan relevantes como la influencia del tratamiento conceptual y del enfoque de enseñanza sobre la selección deliberada de *testing objects* o el tipo de tareas que se plantean (*hands-on* vs *minds-on*).

Asimismo, consideramos que comparar SEAs permite a los docentes e investigadores indagar sobre cuáles son las tareas concretas se plantean en diferentes propuestas de enseñanza y analizar sus similitudes y sus singularidades, lo que suele ser inspirador de cara al diseño. Además, la comparativa favorece que, tanto docentes como investigadores, adquiramos un amplio abanico de tareas sobre un mismo fenómeno a trabajar, permitiéndonos, por tanto, seleccionar cuál es la que más nos interesa de acuerdo con nuestros objetivos de enseñanza-aprendizaje para nuestro contexto de aula concreto.

En definitiva, y respondiendo a la segunda pregunta de investigación, queremos destacar que la comparación de SEAs debe compatibilizarse con la revisión de la literatura en la fase preliminar del diseño de SEAs, pues ayuda a clarificar aspectos esenciales para el diseño de una SEA y a seleccionar aquellos que consideremos como más adecuados para nuestros contextos. Además, el estudio de tareas concretas puede ser una fuente de inspiración de cara al diseño de una SEA propia.

En cuanto a la tercera pregunta, la metodología desarrollada en este trabajo pone de manifiesto que, por su sencillez y aplicabilidad, puede ser útil tanto para los investigadores como para los docentes, destacando, además, que dicho proceso no supondría una sobrecarga en el quehacer diario, sino la sistematización de un mecanismo cotidiano como es la búsqueda de SEAs y tareas concretas compartidas por otros docentes/investigadores.

A modo de agenda futura de investigación, queremos señalar que en este artículo no hemos abordado algunos aspectos esenciales de la comparativa de SEAs, como por ejemplo: qué lleva a un docente a elegir un enfoque conceptual (densidad/fuerzas) frente a otro; qué criterios utiliza para seleccionar una tarea u otra; o qué proceso de adaptación realiza para transferir a su aula las SEAs y tareas previamente buscadas. Cabría mencionar, asimismo, que estos aspectos podrían ser estudiados en cursos de formación de docentes, como así muestra la literatura didáctica (Cortés-Galera et al., 2016; De Jong & van Driel, 2007).

6. Estudio 3. Pre-Service Teachers' Flow and Emotional Climate during a Teaching-Learning Sequence about Floating and Sinking Phenomena

6.1. Introduction

Traditionally, the evaluation of the effectiveness of teaching and learning sequences (TLS from now on) has focused more on the cognitive than on the affective aspects (Alsop & Watts, 2003; Nicolaou et al., 2015). However, in the recent research the interest in evaluating the affective dimension has emerged, due to the steadily increase of our knowledge on the role of emotions in learning (Bellocchi et al., 2014; Pekrun & Linnenbrink-Garcia, 2014). This has led to it currently being a topic of great interest for Science Education (Jeong & González-Gómez, 2021), with studies being carried out at different educational levels: from primary and/or secondary school students (Dávila-Acedo et al., 2021; Dávila-Acedo et al., 2021) to pre-service teachers (Bellocchi & Amat, 2022; López-Banet et al., 2021).

Regarding pre-service teachers (PSTs from now on), the importance of analyzing emotions is twofold: first, as future reflective teachers and, second, as university students in training (Papaevripidou et al., 2017).

From the perspective of PSTs as future teachers, it is important that they become aware of their own emotions while learning (teachers as learners) because it will make them recognize and anticipate the emotions of their future students, in addition to recognizing that learning science produces different emotions, such as interest and satisfaction in learning, as well as surprise, insecurity or boredom (López-Banet et al., 2021). It is also important that they learn to identify their own emotions, as an initial step of self-regulation (Salovey & Mayer, 1990) because when they become teachers it will affect them, although with a special emphasis during the first years of the profession (Bellocchi, 2019). The ability to regulate oneself (self-regulation) plays an essential role in personal development as it favours the growth of the qualities that each of us possesses and allows us to address our limitations (Sala et al., 2020). That is why the scientific literature has shown in recent years the importance of setting tasks where the awareness and regulation of students' learning and emotions are one of the backbones of the TLSs (Jiménez-Liso et al., 2021; Lai et al., 2018; Sanmartí, 2020; Thomas, 2003). Thanks to this type of tasks, PSTs will have the opportunity and time to reflect, either cognitively or emotionally, on what they have learned and what they have not learned during the course of the TLSs. Moreover, the results of these tasks can serve also to us, as teachers educators and educational researchers, to analyze how the TLS is working, thus eliminating the need to add teaching assessment instruments that are unrelated to the TLS (Jiménez-Liso et al., 2021).

In the second perspective, as university students, most of the research focuses on identifying what emotions PSTs remember in relation to their science learning in secondary education (Brígido et al., 2013; Marbà, 2008). These emotions could have been determinant for the choice of a university career. However, what interests us most in this work is closely related to emotions linked to specific teaching proposals. Some studies focus on analyzing the effect of innovations such as flipped classroom (Jeong & González-Gómez, 2021) or of a single inquiry task (Ezquerra et al., 2022) on the emotions of PSTs. In our specific case, however, we want to analyze situational emotions, chronologically over the course of a TLS with a model-based inquiry teaching approach (Jiménez-Liso et al., 2021).

In order to analyze these two perspectives, and being aware of the variety of definitions of the term emotion, in this study we assume the neuroscientific view that they are not reactions to incoming data but part of our predictive process (Clark, 2015; Wilkinson et al., 2019) as we consider it consistent with classic studies on the pedagogy of wonder (Legrand, 1969). Similarly, the classifications and categorizations of emotions are also diverse, with a very psychological bias for the most part. Generally speaking, classifications usually refer to emotions in terms of positive (those to favor) or negative (those to minimize), without considering that, in the educational context, the approach should be more sociological (Bellocchi & Turner, 2019), analyzing the emotions in terms of their effects in learning. That is, what emotions favor or hinder, even block, students' learning.

In this sense, theoretical frameworks such as emotional climate (Bellocchi et al., 2014; Fraser et al., 2021; Hong et al., 2021; Rinchen et al., 2016) and flow theory (Csikszentmihalyi, 2014) could provide, on the one hand, information about the emotions that favour a good classroom environment which, in turn, fosters productive learning (Darling-Hammond & Cook-Harvey, 2018) and, on the other hand, from a situational perspective (Inkinen et al., 2020), information on the moments when engagement occurs.

Taking all this into account, the study presented here uses these two frameworks in order to assess the self-reported emotions of PTSs from a sociological perspective, as they chronologically emerge along a TLS on the topic of floating and sinking. Our intention is to add to the existing literature information on the emotions experienced by PSTs when experiencing in first person a TLS based on inquiry and modelling, what links can be made between the different emotions and the consequences of these links in terms of emotional climate and flow.

6.2. Theoretical framework

In addition to the role of emotions in the field of education, the theoretical frameworks that underpin this study are emotional climate and flow, as they provide us with the dimensions with which we analyse the PSTs' self-reported emotions along the TLS. This is why in the following sections we clarify what we understand by emotional climate and flow, what their characteristics are and what are the associated emotional states.

6.2.1. Emotional climate as a framework for understanding the learning environment during a TLS

Emotional climate is a topic that falls within the *learning environments* line of research (Tobin et al., 2013) and is characterised by the fact that it has been little studied with PSTs (Bellocchi et al., 2013; Olitsky, 2013). It has traditionally been defined as a collective state of emotional arousal in which participants in an organisation or, in this case, a classroom, develop a collective identity, putting aside the self for the we (Bellocchi et al., 2014).

Emotional climate has been associated with increases in motivation (Fraser et al., 2021); greater development of self-esteem (Hong et al., 2021); improved self-efficacy and achievement (Retana-Alvarado et al., 2018); and, finally, with positive attitudes towards science (Bellocchi et al., 2014). In view of this, one might ask what characteristics of the classroom environment are related to the benefits mentioned above. In response, there is research that has identified factors that favour a good emotional climate.

Bellocchi et al. (2013) found that it is necessary to foster interactions between students. Hong et al. (2021) highlight the essential role of the teacher in providing explicit support to students, encouraging them to help each other and, at the same time, discouraging disrespect and belittling. Likewise, Bellocchi et al. (2014), analysing which specific tasks foster a good emotional climate, found that a positive state of emotional climate can be associated with tasks where role-plays, discussions or POE-type sequences are encouraged. In addition to these indications, it has been concluded that a decisive aspect for experiencing a good emotional climate is students' engagement (Rinchen et al., 2016) which has multiple dimensions (emotional, behavioural, cognitive, etc.) (Fredericks et al., 2016; Jiménez-Liso et al., 2021).

Similarly, the scientific literature has associated a favourable state of emotional climate with certain emotional states, such as happy, surprised, wonder, gaiety and joy. A poor emotional climate, however, is associated with emotional states such as sadness, fear or anger (Bellocchi et al., 2014). This indicates that there are certain emotions that facilitate the experience of a good emotional climate and others that, on the contrary, hinder it.

Therefore, as can be seen in the previous paragraphs, the scientific literature has studied which classroom characteristics and emotional states favour a good/poor emotional climate. A new step in this direction would be to analyse, at a finer scale, which specific moments of a TLS favour it and which hinder it.

6.2.2. Flow Theory as a framework for identifying pre-service teachers' engagement during the TLS

In the previous section we highlighted the emotional climate framework, but another interesting theory that adds to research in the effect of emotions in learning is the flow theory (Csikszentmihalyi, 1990).

The experience of flow influences performance (Shin, 2006), an individual's commitment to the task (Larson, 1998; Nakamura, 1998; Whalen, 1997), student success (Ellwood & Abrams, 2018), motivation (Chang et al., 2012) self-esteem (Hofferber et al., 2016), and, ultimately, greater learning (Rachmatullah et al., 2021). However, despite the benefits outlined here, this theory has not been widely studied in science education or in inquiry-based teaching settings (Ellwood & Abrams, 2018).

Flow theory was first coined by Mihaly Csikszentmihalyi and its development stems from Csikszentmihalyi's interest in situations in which artists and musicians worked for hours at a time with a very high level of concentration (Csikszentmihalyi, 1996). Taking into account the high levels of concentration described, Csikszentmihalyi defined this experience as *the holistic sensation that people feel when they act with total involvement* (Csikszentmihalyi, 1977).

Later, due to the interest in flow theory, Nakamura & Csikszentmihalyi (2002) identified the main characteristics of this experience: clear goals, balance between the challenge provided by the task and the abilities of the individual facing it, feedback, isolation, concentration, enjoyment, loss of time, sense of control, and effortless performance. Of all these characteristics, the scientific literature has tried to characterise which are essential for experiencing the flow (Bressler & Bodzin, 2016; Hofferber et al., 2016; Hong et al., 2020; Rachmatullah et al., 2021), highlighting those of concentration and enjoyment.

In this way, and thanks to the specification of the essential characteristics of the flow experience, a more operational definition of this mental state was arrived at, so that it can be understood as states of high concentration and enjoyment in relation to the task being performed (Montoro, 2014; Montoro & Gil, 2015; Rodríguez-Sanchez, 2009) These two emotional states, concentration and enjoyment, are essential to the experience of flow, which is why they are usually used to identify flow empirically (Montoro & Gil, 2015).

6.3. Goal and research questions

In this paper, we will identify which moments in the progression of conceptual ideas along the TLS show a classroom climate conductive to productive learning and those which have facilitated flow experiences to our PSTs through the analysis of the emotions they acknowledge to have felt and their perception of the learning process. The research questions we posed for this study are as follows:

- What emotions do PSTs report along the TLS about floating and sinking?
- Which key moments of a modeling and inquiry TLS show a more productive emotional climate (learning environment) for cognitive and emotional learning?
- Which key moments of a modeling and inquiry TLS have facilitated the highest (and lowest) number of learners in flow?

6.4. Methodology

6.4.1. Participants and teaching context

The study reported in this manuscript is framed within the subject Science Education I of the Degree in Primary Teacher Education at the University of Almeria, Spain. This subject (3rd and 4th semester of the degree) aims to make PSTs live in first person different Model-Based Inquiry (MBI) TLSs.

One of the TLSs that we make PSTs experience is called *Neither floats nor sinks* (Vokos et al., 2021; pp. 4-5), where we try to get them to build a scientific model that allows them to describe, explain and predict situations in which the floating and sinking phenomena are involved. These phenomena are relevant because, from a very early age, students have experiences about flotation (bath toys that float or sink) that generate the construction of personal ideas (Paños et al., 2022), which are usually unsophisticated and incoherent (Rowell & Dawson, 1977a; Shen et al., 2015). Moreover, many curricula worldwide have incorporated floating and sinking (NCE, 2014; NESA, 2017; NGSS, 2013) as a key context for learning certain content, such as density or the model of forces. Researchers in Science Education have also studied it for decades (Flores Camacho & Gallegos Cazares, 1998; Gao et al., 2020; Ginns & Watters, 1995; Joung & Gunstone, 2010) with the aim of detecting the difficulties that students have with the phenomena of floating and sinking and to put forward proposals to improve the ways of teaching it (Hadjiachilleos et al., 2013; Kawasaki et al., 2004).

Regarding our TLS *Neither floats nor sinks,* we propose to the PSTs an experience in which they not only learn the scientific content related to these phenomena, but also the didactic aspects of how they have learned this content and how it has been taught. In other words, we make a proposal where the scientific content is integrated with the didactic aspects (Jiménez-Liso et al., 2021).

The TLS in question was implemented in the fourth semester of the 2017/2018 academic year for five weeks (20 hours in total). Three university teachers taught it: teacher A had only one year of experience as a teacher of Science Education in teacher training; teacher B had under ten years of experience in this subject/degree; and finally, teacher C had over 25 years of experience in the subject/degree. All three teacher educators belong to the same research group, were fully coordinated and used the same materials, resources and assessment tools simultaneously. A total of 137 PSTs participated and consented to the present research, distributed randomly in three teaching groups: 46 belonged to teacher C's group, 67 to teacher B's group and 24 to teacher A's group. These PSTs are aged between 19-23 years and come from middle-class backgrounds. The sample selected was non-probabilistic and of convenience, based on the availability of time and cases.

In order to have a broad overview of our TLS, the main features are shown below. Prior to its development, we review with the PSTs four key concepts that will be essential for understanding the phenomena of floating and sinking (PR1/2; white boxes in Figure 42). Although these are not tasks of the TLS itself, but are previous ones, we incorporate them in Figure 42 because of their importance for the rest of the TLS. After the review of these initial concepts, we engage PTSs in a complete cycle of inquiry (I; tasks in orange boxes in Figure 42) and another of modelling (M; tasks in green boxes in Figure 42). As for the Figure 42, the boxes (in orange or green) show which tasks are carried out by the PSTs and the ellipses (in white) the didactic objectives for each of those tasks.

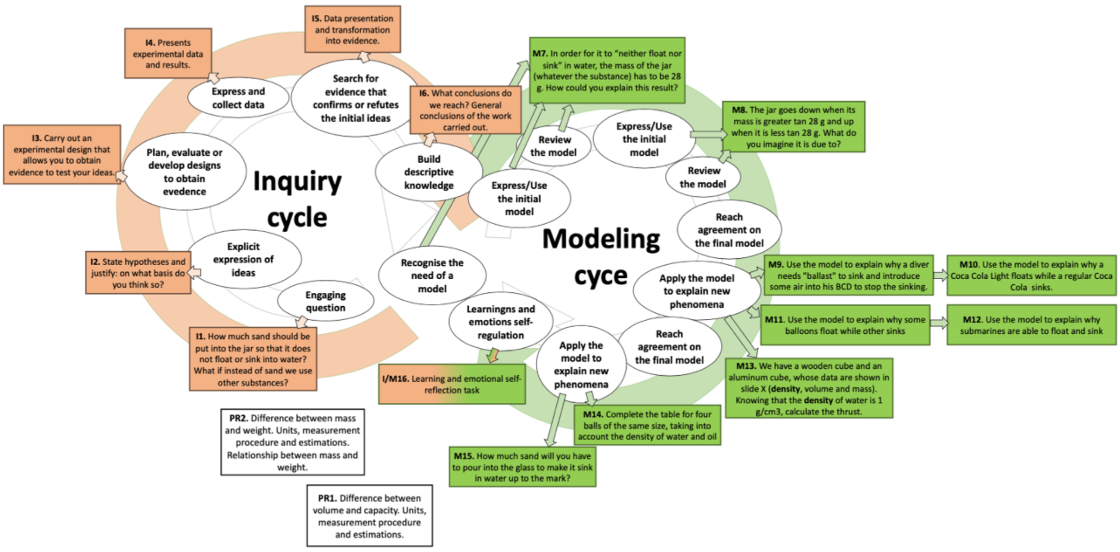


Figure 42. Cycles of inquiry (Jiménez-Liso, 2020; Jiménez-Liso et al., 2020) and modelling (Couso, 2020; Garrido-Espeja & Couso, 2017) in the TLS *Neither floats nor sinks*.

To be more specific, the TLS starts with pre-tasks devoted to clarifying the differences between volume and capacity (PR1) and between mass and weight (PR2), which are not included in the cycles because they are leveling activities used as pre-requisites in order to ensure that all PSTs master these concepts before starting the TLS. After this, we pose a question that is closed, contextualised and for which PSTs cannot do a quick Internet search to solve (I1: How much sand should be put into the jar so that it does not float or sink into water? What if instead of sand we use other substances?) The characteristics of this question encourage PSTs to express their personal ideas and not to respond with academic knowledge (I2). The following tasks encourage PSTs to search for evidence (design experiments, obtain data, analyse them) that allows them to accept or refute these initial ideas (I3, I4 and I5). Finally, descriptive knowledge is constructed, which in this case refers to the fact that, for an object to neither float nor sink in water, the mass must be equal to the volume of the object being submerged (I6). This descriptive knowledge is key to generating the need for a model that explains why it neither floats nor sinks regardless of the substance we use (M7), and then it is possible to quantify the buoyant force (mass of water dislodged when the jar is submerged) and compare it with the weight of the jar, which allow PSTs to build the final model and apply it to different situations (from M9 to M15) of flotation.

It is worth mentioning that, through the TLS, the PSTs build the model of forces to explain the phenomena of floating and sinking. However, since their first explanations for task M7 usually refer to density, we incorporate in the TLS tasks (M13 and M14) addressed to help PTSs reconcile the two models, so that they can make sense of their previous ideas.

6.4.2. Data gathering

This paper is part of a broader work in which we evaluate the TLS *Neither floats nor sinks* according to different factors/objectives. For this evaluation, we have designed a Heuristic Assessment to analyse the products made by PSTs in some tasks during the TLS avoiding the disruption of the learning process, which is made up of the PSTs' drawings with which they try to explain why the jar neither floats nor sinks (I1) the experimental designs made by them (I3), the recordings while the PSTs perform the TLS and, finally, the learning and emotional self-reflection task (I/M16).

In this paper, we will focus exclusively on the information provided by the learning and emotional self-reflection task (I/M16 – Annex V), from which PSTs have to reflect on their learning (what have you learned?) in the key moments of the TLS (how have you learned?) which includes the identification of the emotions perceived in each of these moments (how have you felt in each moment?). This task (I/M16 – Annex V) has the structure of a Knowledge and Prior Study Inventory (KPSI), to which we have added a section for the PSTs to indicate how they have felt, together with sentences (easily recognisable by the PSTs) in which we describe the key moments of the TLS (Table 4). For the construct validity of these key moments, the teachers of the subject proposed different wordings for these descriptions and, through discussion, agreed on the ones they considered the most appropriate. It is very important to note that this is not a task that is performed before and after the TLS, but that the PSTs, once the TLS in question is finished, perform it. For its analysis, we use a non-experimental methodology that is descriptive, comparative (studying differences between two or more groups) and correlational (studying the degree of association between variables) (Mcmillan & Schumacher, 2005).

In the following table (Table 4), we show specifically which are the key moments that make up the TLS about the phenomena of floating and sinking and associate them with the concrete tasks of the TLS presented in Figure 42. We understand key moments as the teaching and learning situations in which the progression of conceptual ideas are promoted and expected.

Table 4. Key moments and tasks of the TLS *Neither floats nor sinks*

	Key moments of the TLS	**Associated tasks (Figure 42)**
KM1	Difference between volume and capacity. Units, measurement procedure and estimates.	PR1
KM2	Difference between mass and weight. Units, measurement procedure and estimates. Relationship between mass and weight.	PR2
KM3	Justify your answer and design the search for evidence to answer: *how much sand should be put into the jar so that it does not float or sink?*	I2, I3, I4, I5, I6
KM4	*Phantom object* model to determine the value of the buoyant force exerted by a fluid on an object.	M7 and M8
KM5	Use of the (weight-buoyant) model to explain the floating or sinking of objects (*can, submarine, balloon, diver...*) immersed in a fluid.	M9, M10, M11, M12

KM6	Physical meaning of density. Use of the (weight-buoyant) model to justify that the comparison between density of the object and the fluid explains whether it floats or sinks.	M13 and M14
KM7	Using the (weight-buoyant) model to predict how much an object floating in a liquid sinks	M15

6.4.3. Data analysis

For the statistical treatment of the data, we have divided the learning and emotional self-reflection task (I/M16 – Annex V) into two parts: on the one hand, the part focused on the PSTs' self-perception of learning (before-after) in each key moment of the TLS (Table 4), for which we have used an ordinal scale from 1 to 5: 1) I do not know anything; 2) I know a little, 3) I know it well, 4) I know it very well, 5) I can explain it to a friend. On the other hand, the part that display the emotions that PSTs associate to these moments. This list of emotions have already been used and validated in previous empirical studies (Jimenez-Liso et al., 2021; Jiménez-Liso et al., 2021) and include rejection, concentration, insecurity, interest, boredom, confidence, satisfaction, dissatisfaction and embarrassment. Both parts (self-perception of learning and emotions) were linked to each of the key moments of the TLS in Table 4.

As for the reliability of the learning and emotional self-reflection task (I/M16 – Annex V) and the data collected (American Pshychological Association, 2001), we used two different coefficients: for the reliability of the results referring to the self-regulation of learning, being ordinal variables, we used Cronbach's coefficient (0.908). For the reliability of the results relating to emotions, being nominal variables, we used the Kuder-Richardson coefficient (0.808). We interpret these two values as indicators of acceptable reliability taking into account the exploratory nature of the study.

To further refine the study of reliability with regard to emotions, we have broken down the learning and emotional self-reflection task into nine sub-sections, taking as a construct in each of them the experience of a particular emotion through the different key moments of the sequence. In this case, the following Kuder Richardson coefficient values are obtained: Rejection: 0.538 - Concentration: 0.886 - Insecurity: 0.812 - Interest: 0.847 - Boredom: 0.878 - Confidence: 0.775 - Satisfaction: 0.818 - Dissatisfaction: 0.826 - Embarrassment: 0.561. The low results in the case of rejection and embarrassment are due to the low variability since very few PSTs report having felt these emotions at some point, as will be seen below.

Finally, in order to do all this statistical treatment we use SPSS (Statistical Product and Service Solutions) software in version 27 and EXCEL, version 16.51. These softwares allow us to perform various calculations and statistics, such as the mean, the standard deviation or the Chi-square statistic. In order to show this in context, we will explain more fully which calculations and statistics we used and for what purpose in the results section.

6.5. Results and discusión

The emotions the PSTs reported to have felt along the TLS are shown in Figure 43, which indicate the percentage of PTSs that report each emotion. In different shades of blue, we indicate those participants who report having felt the emotion only at one key moment and those who report having felt it at two moments and even at more than two key moments along the TLS.

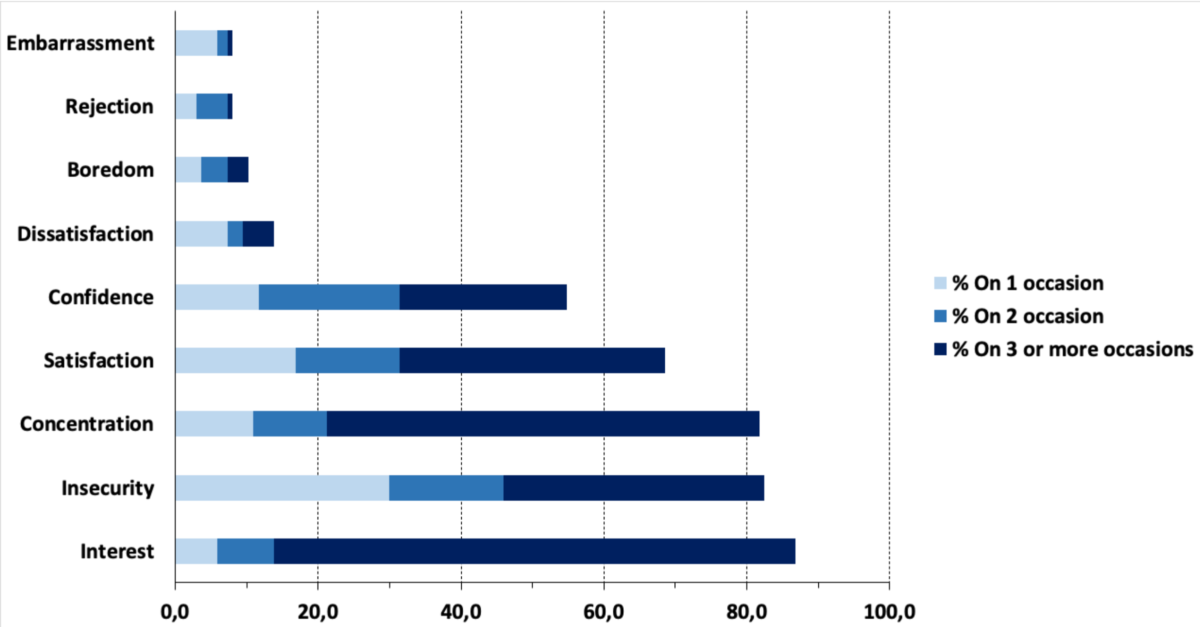


Figure 43. Percentage of PSTs who have experienced each emotion throughout the TLS

In general terms, we can state that the emotions least chosen by the PSTs are embarrassment, dissatisfaction, boredom and rejection, with less than 10% of the PSTs acknowledging having felt them. The emotions that most PSTs acknowledge having felt during the TLS - either once, twice or three or more times - are satisfaction (65%), confidence (55%), interest (>80%), concentration (>80%) and insecurity (>80%), with all of them happening on 3 or more occasions.

This static and unchronological view of the global repertoire of the emotions felt along the TLS (Figure 43) can be complemented with the chronological, dynamic perspective introduced by the theoretical perspectives of the emotional climate and flow frameworks described in the previous section. To do this, we have calculated the number of PSTs (and the percentage) who have experienced the different emotions at each key moment of the TLS (see Table 4). Emotions have been classified taking into account the theoretical perspective of emotional climate and flow. Thus, on the one hand we would find interest, confidence, insecurity, embarrassment and boredom (which will give us information about the moments in which the emotional climate has favoured more productive learning) and, on the other hand, concentration, satisfaction, dissatisfaction and rejection (which will give us information about the moments in which the number of PSTs in a state of flow is greater). To analyse flow, we focus on the emotional states of concentration and satisfaction, using this latter one as a proxy for enjoyment. This is because in previous reserach we have identified that both enjoyment and satisfaction emerged together and undifferentiated in the studetns' epxerience (López-Banet et al., 2021)

6.5.1. Results from the perspective of emotional climate

To answer the second question (key moments that show a more productive emotional climate for cognitive and emotional learning), we consider that those moments with high percentages of PSTs who recognize having experienced interest, confidence and insecurity are associated with a productive emotional climate. This last emotion, insecurity, is included because we understand that insecurity is related to leaving one's comfort zone, which is indispensable in learning. High percentages of embarrassment and boredom could be considered as inhibitors of a good emotional climate.

Next, we show the percentage of PSTs who recognized that they felt each of the emotions associated with the emotional climate (Table 5) and we try to glimpse what possible relationships may have been produced in the different tasks of the sequence.

Table 5. Percentage of PSTs who acknowledge feeling emotions related to the emotional climate at each key moment

N=137	Interest		Confidence		Insecurity		Embarrassment		Boredom	
	n	%	n	%	n	%	n	%	n	%
KM1	79	57,6	28	20,4	38	27,7	**5**	**3,6**	7	5,1
KM2	69	50,3	30	21,9	32	23,4	2	1,5	**10**	**7,3**
KM3	85	62	31	22,6	36	26,3	2	1,5	2	1,5
KM4	88	64,2	30	21,9	37	27	3	2,2	4	2,9
KM5	84	61,3	**34**	**24,8**	39	28,5	1	0,7	4	2,9
KM6	78	56,9	27	19,7	**44**	**32,1**	1	0,7	6	4,4
KM7	**89**	**64,9**	**34**	**24,8**	38	27,7	2	1,5	3	2,2

In Table 5, we can observe that there are two moments in which a greater number of PSTs have experienced the emotions related to a good emotional climate: KM5, where PSTs use the model of forces in order to explain several floating and sinking situations, and KM7, in which again PSTs have to use the model, but this time having been reconciled with the density. Both moments, moreover, coincide with a high learning perception (2.48 and 2.31 respectively) (Table 6, where we show the PSTs' perception of learning before and after experiencing the TLS and the difference between both moments).

KM1 and KM2 (differences between volume-capacity and mass-weight respectively) are, on the one hand, the key moments of the TLS in which the greatest number of PSTs recognize having felt embarrassment and boredom and, on the other hand, where the fewest PSTs recognize feeling interest and confidence. Likewise, KM1 and KM2 are the moments in which PSTs recognize having experienced the least learning (1.80 and 1.83). Therefore, the data seem to suggest a possible relationship between the perception of learning and the emotional climate: the greater the perception of learning, the better the emotional climate and vice versa.

KM6 (reconciliation between density and force models), on the other hand, also seems to be an important moment for the TLS, as there is a peak in the number of PSTs who consider themselves to have felt insecure. This, far from having negative connotations, could indicate that they can express their insecurities by being in a good emotional climate.

Table 6. PSTs' perception of initial and final knowledge after experiencing the TLS (learning leap)

Key moment	Before		After		Difference BEFORE-AFTER
	Average	sd	Average	sd	Average
KM1	2,12	0,900	3,95	0,780	1,83
KM2	2,15	1,035	3,95	0,918	1,8
KM3	1,65	0,836	4,00	0,915	**2,35**
KM4	1,33	0,758	3,94	0,968	**2,61**
KM5	1,48	0,875	3,96	0,914	**2,48**
KM6	1,63	0,975	3,65	0,916	2,02
KM7	1,49	0,860	3,80	0,941	2,31

This joint treatment of emotions seems to indicate that there are moments that have favoured a good emotional climate and, therefore, a productive learning environment (KM5, KM6 and KM7) as opposed to other moments in which it has suffered (KM1 and KM2), all of them being linked to a greater/lesser perception of learning on the part of the PSTs.

6.5.2. Results from the perspective of flow

As we indicated previously, the two main dimensions with which we identify that PSTs have felt flow are concentration and satisfaction, while dissatisfaction or rejection represent those moments in which PTS's flow suffers. Thus, a high percentage of PSTs who recognize that they feel concentration and satisfaction and a low percentage of them who have felt dissatisfaction and rejection would allow us to detect the moments of greatest collective flow. Table 7 shows the percentage of PSTs who said they felt the aforementioned emotions (concentration, satisfaction, dissatisfaction and rejection) so that we can intuit what relationships may have been established in relation to the key tasks of the sequence.

Table 7. Percentage of PSTs who recognise that they feel emotions related to the flow at any given time

N=137	Concentration		Satisfaction		Dissatisfaction		Rejection	
	n	%	n	%	n	%	n	%
KM1	68	49,6	38	27,7	2	1,5	**5**	**3,6**
KM2	68	49,6	42	30,7	3	2,2	4	2,9
KM3	80	58,4	**52**	**38**	7	5,1	1	0,7
KM4	78	56,9	43	31,4	**11**	**8**	1	0,7
KM5	**81**	**59,1**	46	33,6	7	5,1	3	2,2
KM6	68	49,6	42	30,7	7	5,1	3	2,2
KM7	75	54,7	47	34,4	6	4,4	2	1,5

Table 7 indicates that the moments in which there is a higher number of PSTs experiencing concentration and satisfaction are KM3 (justification and search for evidence to accept or refute their answers) and KM5 (use of the model of forces to explain different phenomena), both coinciding with a high perception of learning (2.35 and 2.48; Table 6).

In moment KM4, the highest number of PSTs perceive themselves to have felt dissatisfaction, which, if we look at Table 5, coincides with a high percentage of insecurity. It is also the moment in which there is the greatest jump in learning between before and after (2.61; Table 6).

The relationships that have been tentatively established between the emotions related to emotional climate and flow and the coincidences between learning perception-emotional climate/flow indicate the need to study the correlations that occur between them.

6.5.3. Correlations produced between emotions and self-perceptions of learnings

To test whether there is a relationship between the different emotions framed within the flow theory and the emotional climate, as well as the relationship between these same emotions and the perception of learning (before-after), we have done a correlational study. As these are categorical variables (nominal in this case), the statistics we will use will be framed within the non-parametric tests. To analyze which emotions are related to each other, we have used the Chi-square contrast statistic (which tells us the degree of certainty with which the emotions are related). To find out the degree of association, that is, the intensity with which the correlation between the different emotions occurs, we used the Phi statistic. In addition to allowing us to know the degree of association (normalized, between -1 and +1), this last statistic has also indicated the direction of the association (direct or inverse), provided that we have 2x2 tables or tables of association between dichotomous variables.

Table 8 shows that confidence correlates negatively with insecurity at all points in the sequence. These data seem to indicate, therefore, that as confidence decreases, insecurity increases and vice versa. Table 8 also shows that, although at first we had only related independently the emotions that fall within the flow theory and those related to emotional climate, there are also correlations and crossovers between both types of emotions. A clear example is the correlation between confidence-satisfaction (which correlates positively in all moments except KM5) and interest-concentration (positively correlated in all moments except KM4). Likewise, insecurity correlates negatively with satisfaction (KM2, KM3 and KM6) and positively with dissatisfaction (KM1, KM4, KM5 and KM7). These data seem to indicate that, on the one hand, emotions such as confidence and interest (associated with a productive emotional climate) favour the experience of flow (concentration and satisfaction) and, on the other hand, that insecurity hinders this experience.

If we look at the emotional climate, interest correlates negatively with boredom in all moments except KM5. In this same moment, the perception of learning correlates with two emotions: boredom (emotional climate; only in KM5) and dissatisfaction (flow; in addition to KM5 in KM4). These last two correlations could be indicating, as signalled in previous works (Jiménez-Liso et al., 2021; López-Banet et al., 2021), that, far from considering boredom and dissatisfaction as something negative, it could be considered as an indicator that PSTs associate to slow thinking, that is, with moments of explanation, where models are constructed, and with their use in other contexts.

It is also interesting to note that the perception of learning also correlates positively with concentration at KM1 and with satisfaction at KM7, which could be confirming, on the one hand, the need to engage in order to learn and vice versa and, on the other hand, that learning, although they have experienced different emotions until it is achieved, produces satisfaction (Jiménez-Liso et al., 2021).

Table 8. Degree of association between emotions

	Learning (Before-After)	**Rejection**	**Concentration**	**Insecurity**	**Interest**	**Boredom**	**Confidence**	**Satisfaction**	**Dissatisfaction**
Rejection									
Concentration	T1: 0,331								
Insecurity		T2: 0,314							
Interest		T7: -0,166	T1: 0,230 T2: 0,206 T3: 0,286 T5: 0,224 T6: 0,185 T7: 0,193						
Boredom	T2: 0,358 T5: 0,332		T2: -0,169	T1: -0,144 T4: 0,187	T1: -0,204 T2: -0,283 T3: -0,156 T4: -0,232 T7: -0,204				
Confidence				T1: -0,274 T2: -0,251 T3: -0,283 T4: -0,243 T5: -0,325 T6: -0,223 T7: -0,243	T7: 0,209				
Satisfaction	T7: 0,363		T3: 0,202 T4: 0,175	T2: -0,180 T3: -0,194 T6: -0,186	T3: 0,209	T6: -0,142	T1: 0,212 T2: 0,184 T3: 0,260 T4: 0,174 T6: 0,347 T7: 0,297		
Dissatisfaction	T4: 0,462 T5:0,373	T1: 0,301		T1: 0,196 T4: 0,244 T5: 0,294 T7: 0,345			T4: -0,156 T5: -0,133	T3: -0,181 T5: -0,165 T6: -0,154 T7: -0,155	
Embarrassment		T2: 0,340		T2: 0,220 T3: 0,204 T4: 0,246	T4: -0,201 T7: -0,166	T1: 0,308			T4: 0,323 T5: 0,370 T6: 0,370

				T7: 0,196					T7: 0,569

6.6. Conclusions

In all our instructional TLSs for both initial teacher education and non-university level we include tasks where students reflect on their perception of what they have learned, how they have learned it and what they have felt. In this paper, we analyse the PST's responses to this task in terms of the theoretical framework of flow theory (Csikszentmihalyi, 1990) and emotional climate (Bellocchi et al., 2014), which has allowed us to identify which moments of the TLS promote a more productive emotional climate for learning (both cognitively and emotionally) and which moments foster a greater number of PSTs in flow.

Thus, with the information obtained from the emotions interest, confidence, insecurity, embarrassment and boredom and their combination with the perception of learning, we have been able to interpret which were the tasks of the TLS whose emotional climate most favoured learning. In this sense, at first, we considered that the moments that favoured this emotional climate were KM5 (use of the (weight-buoyant) model to explain the floating or sinking of objects (*can, egg, balloon, diver*...) immersed in a fluid) and KM7 (using the (weight-buoyant) model to predict how much an object floating in a liquid sinks), given that they produced the highest percentages of PSTs with confidence and interest and coincided with high values in the perception of learning (Table 5). The correlations allowed us to confirm that KM7 produced an adequate emotional climate for learning, as there was a positive correlation between the emotions confidence and interest (Table 8).

Concerning the second question, with the information obtained on the emotions concentration, satisfaction, dissatisfaction and rejection and on the perception of what was learned in each moment, we have been able to interpret the moments of the TLS (Table 7) in which there was a greater number of PSTs experiencing flow: KM3 (Justify your answer and design the search for evidence to answer: how much sand should be put into the jar so that it does not float or sink?) and KM5 (use of the (weight - buoyant) model to explain the floating or sinking of objects immersed in a fluid), since the highest percentages of the emotions concentration and satisfaction were produced. This result was confirmed in the correlations for KM3, where concentration-satisfaction correlated positively, and, in addition, satisfaction-dissatisfaction also correlated negatively. In KM4 (Phantom object model to determine the value of the buoyant force that a fluid exerts on an object) there was also a positive correlation between concentration and satisfaction, so we can affirm that this moment has also led to the appearance of flow among many PSTs. This moment is very significant since, in addition to flow, it produces the highest number of PSTs who perceive dissatisfaction (Table 7) and insecurity (Table 5) and the greatest jump in learning between before and after (2.61). This seems to confirm what has been published in other works (Jiménez-Liso et al., 2021; Jiménez-Liso et al., 2021) in which it is stated that insecurity and dissatisfaction are indicators that PSTs recognize leaving their comfort zone when learning.

Thus, we have been able to observe that the emotions related to emotional climate and flow intersect and link with each other, so that confidence and interest (associated with emotional climate) seem to help to experience concentration and satisfaction (associated with flow) and vice versa. This seems to be in line with the scientific literature, given that research such as that presented by Rinchen et al. (2016) associates a good emotional climate with engagement, which, as mentioned in the theoretical framework, is related to states of flow.

Given the results obtained here, we could affirm that there are three key moments in the TLS: KM3, where PSTs followed a complete cycle of inquiry to answer the question: how much sand should be put into the jar so that it does not float or sink?; KM4, where PSTs build models to explain why a jar neither floats nor sinks; and KM7, where PSTs use the model built previously to explain other situations. These results are relevant for the area of Science Education as they would indicate that inquiry and modelling processes, widely recommended scientific practices (European Commision, 2015; NRC, 2012), seem to have the necessary characteristics to foster the right emotional climate for productive learning and for PSTs to experience flow, which may have an impact on motivation (Chang et al., 2012), attitude towards science (Bellocchi et al., 2014) and increased learning (Rachmatullah et al., 2021).

We would also like to highlight that the results found here seem to show us the need to link the processes of metacognition, understood as someone self-reflection on their own learning processes, not only at a cognitive (i.e. analysing the role of metacognition in cognition) or pedagogical level (i.e. what sort of teachers' feedback promotes metacognition), but also at an emotional level. Precisely, we consider that the contribution of this study to the literature in the field is this connection with the emotional dimension of metacognition. The relation between students' perception of learning and student's emotional reporting that we analyze in this study supposes the exploration of this phenomena and tries to contribute to our understanding of the emotional part of metacognition. If emotions are important for learning, metacognition should take them into account, too. By analyzing our own emotions and their association with our perception of learning we tried not only to investigate the relation among the two for research purposes, but also to help our students, which are teachers to be, to realise this important and not intuitive connection. This will help them to understand and regulate better their own emotions as learners, what we hope it will also help them to support their future pupils' understanding and regulation of their own emotions.

Finally, and with a view to future research, we believe that it would be necessary to study the phenomenon we are discussing here in greater depth. To this end, we will study, on the one hand, whether the task provides clear goals, challenge-skill balance, etc. (aspects necessary to experience flow), and, on the other hand, the interactions that took place between student-student and teacher-student, as these will allow us to analyse the feedback given or received. This last aspect, the feedback, has been seen as an essential aspect to facilitate (trigger) or hinder (inhibitor) the experiences of flow and the emotional climate, which provides a relevant framework for our future research.

SECCIÓN III

7. General conclusions

In the *Introducción y objetivos de investigación* section of this Doctoral Thesis, we set out the general objective of identifying the design principles that have guided us in designing the TLS *Neither floats nor sinks*. In order to meet this objective, from a DBR or design-based research perspective, we have proposed three studies with their respective research questions.

In the first study of this Thesis, we carried out a systematic review to characterise and describe the contributions made in the didactic literature about the phenomenon of floating and sinking. In the second study, we have presented a comparative description of five TLSs based on didactic research on the phenomenon of floating, thanks to which we have extracted their main characteristics and shown that the comparative of TLSs can be a valuable resource for both teachers and researchers framed in the DBR methodology (preliminary phase). Finally, in the third study, we analysed the effect of our TLS on floating (*Neither floats nor sinks*) on the classroom climate and flow recognised by pre-service teachers by analysing their perception of what they have learned and how they have felt at different moments of the TLS.

The structure we have proposed for this Doctoral Thesis, where each study has been presented as a complete investigation, has led us to include the conclusions of each of the studies in their respective chapters. This is why, in the section that we now develop, we want to reflect on those conclusions that are of a general and cross-cutting nature. These conclusions will help us, in the following section (see Implicaciones), to identify the design principles that have guided us and to redesign the TLS analysed in studies 2 and 3 to adapt it to children in Primary Education (second cycle, 8-9 years), this last proposal being a challenge we were presented with at the ESERA 2021 symposium: *Floating and sinking: different approaches for research-based teaching learning sequences*[3].

The general conclusions that emerge from the three studies are as follows:

1. **The limited consensus and lack of coherence between the classroom proposals in the literature and the recommendations of didactic research on what and how to teach flotation show that the gap between educational research and didactic innovation challenges the research community in Science Education.**

[3] Symposium organised by María Rut Jiménez Liso, Digna Couso and Francisco José Castillo Hernández, with Laurence Viennot as discussant. The symposium brought together the authors of the TLSs that appear in Study 2 of this Doctoral Thesis, with the exception of the SEA Sink or Float.

The phenomenon of floating and sinking has been widely studied since the 1970s, which has allowed us to study, based on the analysis protocol (Annex II), aspects as relevant for the design of TLSs on floating as the alternative conceptions that students of different ages have, the context chosen to address floating, as well as the testing objects proposed, their conceptual treatment (density or forces), the most common teaching approaches for their teaching and, finally, whether the TLSs proposed in the literature involve a process of evaluation of their effectiveness or not.

Thus, the didactic literature shows consensus on three of the aspects mentioned above: alternative conceptions, conceptual treatment and the context chosen to address floating. Concerning the vast amount of research on alternative conceptions, we find that they are presented in a disjointed way, without a theoretical or empirical proposal for learning progression, which would allow teachers to know which is the most appropriate way to learn the concepts linked to floating.

There is consensus in the conceptual treatment given in the didactic literature to the phenomenon of floating: density. This consensus, however, is not consistent with the numerous investigations on alternative conceptions that show the difficulties of students due to the simultaneous control of three variables (density, mass and volume) and the direct (mass) and inverse (volume) relationships that are established between the three. Moreover, if we seek coherence with current teaching approaches, which focus on the development of key ideas and scientific practices, the density approach would fail to take advantage of floating and sinking as a phenomenon for the construction of a central model (the force model) and its progressive sophistication over the school years.

The context chosen to deal with flotation is of great relevance as, among other things, it greatly influences the type of testing object to be used. In the case we are dealing with here, the context par excellence refers to the flotation of objects in the water, with very few occasions in which it is carried out in another liquid and practically absent in gases. As is the case with the conceptual treatment, the practically unanimous decision to deal with floating in liquids would be ignoring the context provided by air, even though it is close and daily for the students (for example, balloons with hot air or helium).

Among the disagreements found in the literature review, we highlight the multitude of testing objects (mostly with a daily nature) used for the same context (objects floating or sinking in water), which would seem to show the researchers' interest in contextualising TLSs as much as possible without a clear paradigmatic phenomenon, beyond the fact that there are objects that float and others that sink in different fluids.

Similarly, the literature also shows a palpable dissent in the teaching approach, mainly due to the very evolution that the area of Science Education has undergone: from more traditional proposals linked to behaviourism (direct instruction experiment) in the early years to the more current socio-constructivist ones (teaching approaches based on scientific practices of enquiry, modelling, etc.).

The implementation and evaluation of TLSs on floating have also undergone an evolution similar to teaching approaches. While researchers were initially concerned solely and exclusively with publishing TLSs or single activities without evaluating the effect they produced, we have subsequently found publications that focus on implementing and evaluating the effectiveness of TLSs on floating.

We could say, in conclusion, that the review of the didactic literature has allowed us to glimpse that, both in floating and presumably in any other topic of school science, Science Education should put more focus on the transparency of the design decisions taken, as well as on the search for consensus and coherence with current research recommendations. The aim of this would be to facilitate its transfer to the classroom and teaching practice, thus contributing to narrowing the gap between research, educational innovation and teaching practice.

2. Conceptual treatment and teaching approach are the most influential design principles when designing TLSs on floating and sinking.

The systematic review of the didactic literature (Study 1), complemented by the comparative description of TLSs (Study 2), has allowed us to clarify the most relevant variables to be analysed both in didactic research and in TLSs on floating: alternative conceptions to be put into conflict; conceptual treatment (density/forces); types of testing objects (daily, purpose-designed or simulated); the number of testing objects; the number of tasks in TLSs; and the teaching approach guiding them. The results obtained in the preliminary studies have shown that the combination of two of these variables, namely the conceptual treatment and the teaching approach, condition the design of the TLSs on flotation, with repercussions on the other variables.

Thus, TLSs that use density as the concept to be learned by students and the inquiry-based teaching approach without modelling intention need to bring into conflict a high number of alternative conceptions (associated with each of the variables involved), which leads, on the one hand, to the use of a high number of testing objects and, on the other hand, to the use of hands-on tasks where descriptive knowledge is built. In contrast, TLSs that use a force-based conceptual treatment and the modelling teaching approach (and its combination with inquiry) do not need to bring into conflict as many alternative conceptions as in the previous case, so the number of testing objects is drastically reduced. Similarly, tasks are not only experimental (hands-on) but also of a more modelling nature (minds-on) so that students can explain and justify the model, as well as different situations.

Therefore, the decision to opt for a conceptual treatment (density/forces) and a teaching approach, besides not being trivial as it is a crucial aspect for the design of the TLS, conditions its transfer to the classroom depending on the duration and the knowledge of the teachers required.

3. **The preliminary design-based research phase (DBR) should be complemented by comparative descriptions of TLSs, which would give systematisation and methodological value to a common action of teachers: drawing inspiration from available activities and TLSs.**

In conclusion 1 of this section, we highlight the difficulty of transferring research results to the reality of the classroom. The comparative description of TLSs and the results we have found from it could be considered a complementary resource, in the pre-design phase, to the already traditional bibliographic searches or adaptations to the school context. At the same time, its simple methodology provides methodological value (systematisation) from the point of view of DBR and didactic value due to its usefulness for the design and/or adaptation/modification of SEAs.

Systematically analysing specific research-based TLSs on the same phenomenon has allowed us to identify the similarities and differences in the tasks they pose, which helps both teachers and researchers to broaden the range of tasks with which to address the same phenomenon and adapt the selected tasks to the needs and characteristics of their context.

Last but not least, the methodology developed in the comparative description has meant making visible and, above all, operationalising an action implicit in the design (search for other TLSs), so it does not imply an extra action but its systematisation.

4. **The emotional aspects of classroom climate (interest and confidence) and flow (concentration-satisfaction) provide indicators of the effect of the TLS *Neither floats nor sinks* and allow the identification of its key moments from the learner's perspective: the experimental design to look for evidence and the use of the model to explain and predict.**

Traditionally, metacognition processes have been associated solely and exclusively with cognitive aspects. However, didactic literature has shown that emotions also play an active role in learning, so metacognition should consider the emotional part. In this sense, our TLS on floating (*Neither floats nor sinks*) incorporates a task in which future teachers have to reflect on the learning they have experienced during the TLS and identify which emotions they have experienced.

Overall, future teachers perceived themselves to have learned throughout the TLS about floating, with more pronounced jumps occurring at moments where, for the most part, future teachers also acknowledged feeling flow (concentration and satisfaction) or a good classroom climate (interest-confidence): experimental design to look for evidence to answer the initial question (KM3), using the model to explain what happened (KM5) and using the model to predict new situations (KM7).

This, on the one hand, allows us to identify a series of indicators that are useful for both teachers and researchers within the DBR framework and, on the other hand, key moments of the TLSs (based on inquiry and modelling) in terms of the emotional framework of the classroom climate and flow. Both frameworks are interrelated since, for students to experience flow, a good classroom climate is necessary to generate confidence/engagement and vice versa. As we will see below, this conclusion has direct implications for design since it allows designers to reflect on what emotion can be produced and at what point in the sequence it is most interesting for it to occur.

5. **The didactic analysis at macro (didactic research results), meso (TLSs designs based on didactic research) and micro (effects on variables associated with learning) levels in the teaching and learning of the floating and sinking phenomenon is a contribution to research in Science Education area from a DBR perspective. This same analysis process can be replicated in any other science topic to inform the design of TLSs based on literature and research.**

At a methodological level, we would like to emphasise the idea that the organisational structure we have proposed in this Doctoral Thesis is in itself a contribution to Science Education. Our area of knowledge has many lines of research, with the teaching of specific topics (forces, chemical change, living beings, plate tectonics, etc.) being one of the most important due to its proximity to the classroom.

In this sense, we consider that, in order to be clear about what and how to teach, it is essential, firstly, to find out what we know about the teaching and learning of the topic according to the existing literature (macro-level); at a second level (meso), to land on the comparison of concrete TLSs based on research on the topic to be taught in order to glimpse how the research results translate into concrete tasks; at the third and last level (micro), to evaluate the effectiveness of the TLSs regardless of the learning variable we are talking about (emotional, cognitive, etc.). All of this, moreover, with the firm objective of proposing new educational proposals, which, of course, will have to be implemented and evaluated again.

We believe that carrying out this exhaustive groundwork prior to the design of TLSs, as well as helping us to detect consensus and dissent in the field, can influence the number of pilots and iterations that TLSs designed from the DBR methodology usually follow, possibly reducing the magnitude of these costly implementations in the classroom. With this in mind, we encourage ourselves and the rest of the research community to replicate this same research structure with various science topics in future doctoral theses or research projects.

8. Implicaciones

8.1. Identificación de los principios, elementos y herramientas de diseño

Todo el camino andado en la presente Tesis Doctoral nos ha llevado a este momento, en el que nuestra intención es clarificar y compartir con el resto de la comunidad investigadora y educativa cuáles han sido nuestros principios de diseño en la SEA *Ni flota ni se hunde*. De igual forma, la clarificación de dichos principios de diseño nos ha permitido su uso en el rediseño de esta misma SEA con el fin de adaptarla al segundo ciclo de Educación Primaria.

En diferentes momentos de la Tesis hemos indicado que nuestro objetivo general es la identificación de los principios de diseño que nos han guiado, de manera que puedan ser replicados en futuros diseños o utilizarlos como medio para enseñar a los futuros maestros a diseñar (objetivo más ligado a nuestra práctica docente). Al revisar las propuestas de otros investigadores, por ejemplo, en el simposio (Guisasola, Armario, et al., 2021) celebrado en el XI Congreso Internacional sobre investigación en DCE (Lisboa), detectamos diferentes dimensiones en lo que los investigadores suelen denominar como principios de diseño. Si queremos ser capaces de poner orden en el caos que supone el diseño de SEAs, primero hemos de diferenciar niveles de concreción en los principios de diseño.

En el nivel menos concreto situaríamos a los propios principios de diseño, que son los consensos o grandes recomendaciones y sugerencias que surgen de la investigación didáctica para el diseño de SEAs. Un ejemplo de ello sería: *para que se produzca aprendizaje significativo en el alumnado han de expresar y hemos de poner en conflicto sus concepciones alternativas.*

Aunque no dudamos de la relevancia y utilidad de este principio de diseño, si queremos diseñar una secuencia de actividades en torno a ello, sería necesario al menos un nivel más de concreción, que hemos denominado como elementos del diseño. Siguiendo el ejemplo anterior, podríamos decir que el elemento de diseño sería una concepción alternativa concreta detectada en el aula o que conozcamos previamente. Por ejemplo, si hemos detectado que la mayoría de nuestro alumnado confunde masa con peso, tendremos que incorporar a nuestra secuencia actividades tareas que las pongan en conflicto.

Como esa concepción alternativa es muy habitual entre el alumnado de diferentes niveles educativos, las tareas que se diseñen pueden utilizarse de manera generalizada. Pero, ¿sería posible extrapolar este elemento de diseño a otras concepciones alternativas menos comunes? Para dar una respuesta amplia, necesitaríamos un nivel más concreto que denominamos herramientas de diseño. En nuestro caso, la herramienta de diseño sería una tabla interpretativa (no solo descriptiva) que contuviera todas las concepciones alternativas sobre flotación agrupadas por niveles educativos o por similitud en sus causas. Por ejemplo, concepciones alternativas originadas por el fluido (gas o líquido), por las características del objeto (material o forma), etc. (Table 2 del Estudio 1).

Teniendo en cuenta los tres niveles de concreción planteados, cabría preguntar qué tipos principios, elementos y herramientas de diseño hemos de valorar. A las descritas en la literatura didáctica (Guisasola, Ametller, et al., 2021; Guisasola, Armario, et al., 2021; Rivero & López, 2020) incorporamos algunas dimensiones surgidas del Estudio 3 de esta Tesis Doctoral:

- Psicológicos: relacionados con cómo se concibe el aprendizaje y el papel del estudiante (ejemplo, tener en cuenta las concepciones alternativas del alumnado).
- Didácticos: relacionados con cómo se concibe la enseñanza. Por ejemplo, considerar que el enfoque de enseñanza guiado produce más efecto que el autónomo.
- Ideológicos: relacionados con cómo se concibe la finalidad de la educación científica. Por ejemplo, considerar que enseñar ciencias no es una actividad neutra ideológicamente y que los docentes pueden y deben *contaminar* al alumnado con un enfoque crítico de los problemas socioambientales que nos afectan.
- Epistemológicos: relacionados con cómo se concibe el conocimiento en general y las ciencias en particular. Por ejemplo, considerar que la ciencia está en construcción.
- Conceptuales: relacionados con las ideas a aprender por parte del alumnado tras vivenciar la SEA. Por ejemplo, considerar las grandes ideas de la ciencia escolar (Harlen, 2010).
- Contextuales: relacionados con la contextualización de la SEA (ejemplo, usar un barco o un globo para abordar flotación) o con el contexto donde se aplica dicha SEA. Por ejemplo, considerar las características socioculturales y económicas del alumnado, aula, centro, etc.
- Emocionales: relacionados con los aspectos afectivos en los procesos de enseñanza y aprendizaje. Por ejemplo, identificar las emociones que se producen con un enfoque de enseñanza determinado.

Para visualizar toda la información hasta ahora plasmada sobre los principios, elementos y herramientas de diseño, así como las anteriores tipologías, mostramos una panorámica en la Figure 44. En la Table 9, por su parte, identificamos cuáles han sido nuestros principios, elementos y herramientas de diseño con respecto a nuestra SEA sobre flotación y hundimiento de objetos *Ni flota ni se hunde*.

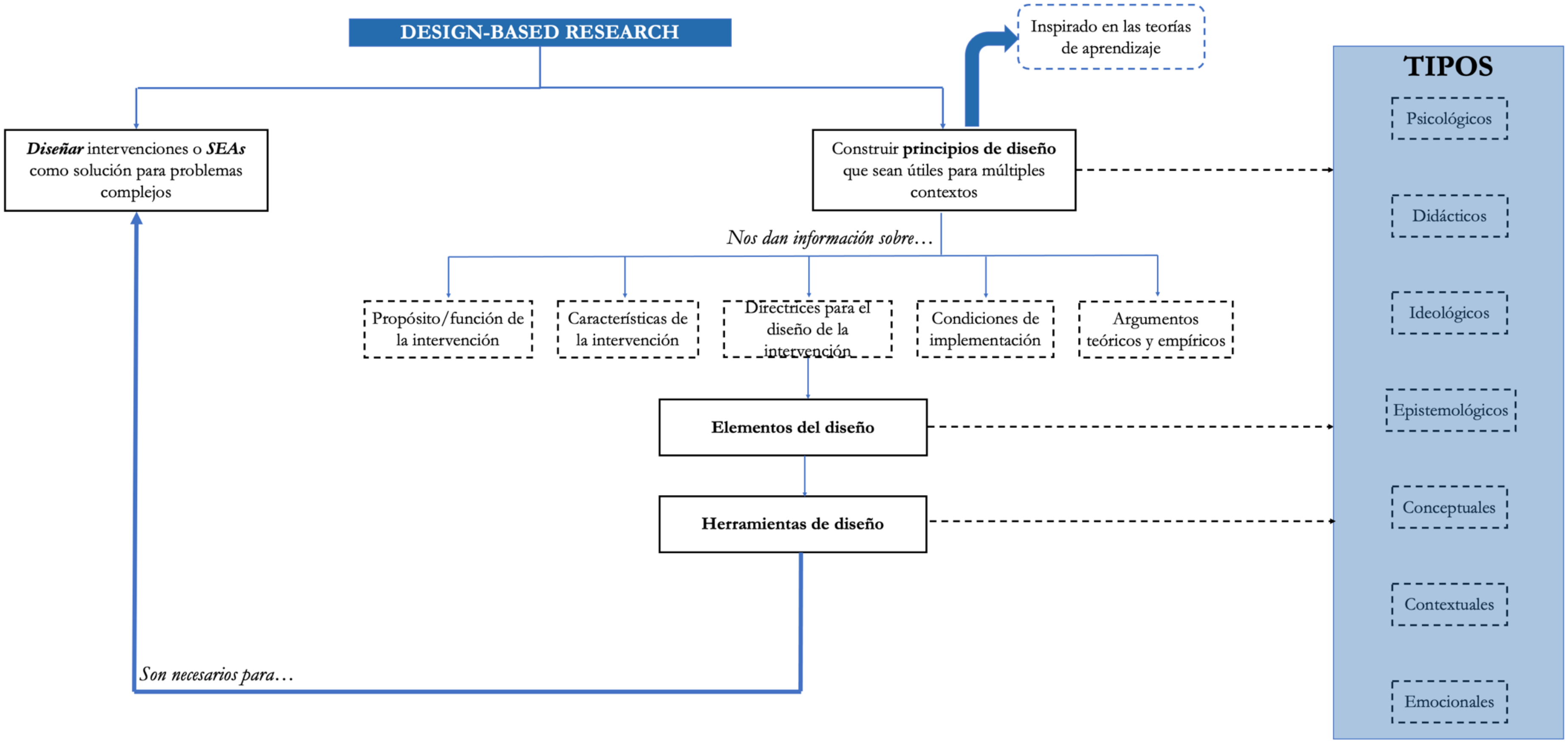


Figure 44. Propuesta de principios, elementos y herramientas de diseño

Table 9. Principios, elementos y herramientas de diseño caracterizados en la secuencia de flotación

Nivel de Concreción (creciente de arriba abajo)		Epistemológicos	Contenidos	Contextuales	Psicológicos	Didácticos	Emocionales	Ideológicos
	Principios	Desarrollar la Naturaleza de la Ciencia (NoS)	Lógica de la disciplina desde el que sabe, *need to know principle*	Contextualizar Buscar relevancia del contenido. *Context based learning*	Tener en cuenta las concepciones alternativas del alumnado. No considerarlas como error (punitivo)	Perspectiva socioconstructivista. Desarrollar un enfoque de prácticas científicas	Reconocer las dimensiones afectivas y emocionales en la enseñanza y aprendizaje de las ciencias	Educación cargada de ideología (no es neutra) y fomentar el enfoque crítico
	Elementos	Enfoques explícito vs implícito de NoS. En nuestro caso, enfoque implícito (aprenden cómo funciona la ciencia a través de la indagación y modelización)	Clarificación conceptual. Seleccionar las grandes ideas a trabajar	Un contexto relevante propio o de la bibliografía. Por ejemplo, un submarino	Una dificultad detectada en el aula o bibliografía. Por ejemplo, confusión masa=peso	Enfoque de enseñanza por indagación y modelización Fases de la indagación: preguntas, hipótesis…	Emociones identificadas en el aula de ciencias cuando se aprende sobre flotación (Estudio 3)	Problema socioambiental sobre la fusión de los icebergs (no aplicado en la SEA para el 2º ciclo de Educación Primaria)
	Herramientas		Mapas (Annex VI) y redes conceptuales (Figures 15 and 16) sobre densidad y fuerzas	Cuadro resumen de todos los *testing objects* tanto de la literautra (Figures 18, 19 and 20)	Cuadro resumen de concepciones alternativas de revisión bibliográfica sobre flotación (Table 2)	Utilizar los ciclos de indagación o de modelización (Couso, 2020; Jiménez-Liso, 2020) para incorporar tareas (Figure 2)	Ciclo emocional ligado a los ciclos de indagación y modelización (Figure 45) que ordena las emociones y las liga a las actividades que las producen	

8.2. Decisiones tomadas para el diseño de la SEA para Educación Primaria

Los principios, elementos y herramientas de diseño que hemos clarificado e identificado en la Table 9 nos permitieron centrar la mirada y focalizarnos en las decisiones que debíamos acometer para rediseñar la SEA *Ni flota ni se hunde* para el segundo ciclo de Educación Primaria:

- Decisiones epistemológicas: la Naturaleza de la Ciencia puede ser enseñada de forma explícita o implícita durante el desarrollo de la SEA. En nuestro caso, decidimos implementar un enfoque implícito, es decir, que los estudiantes aprenderán sobre cómo se construye la ciencia realizando prácticas científicas de indagación y modelización.
- Decisiones sobre el tratamiento conceptual: los Estudio 1 y 2 de la presente Tesis Doctoral muestran una clara tendencia hacia el tratamiento conceptual por densidad en las SEAs sobre flotación a pesar de las muchas dificultades de aprendizaje descritas en la literatura. La experiencia de nuestra SEA sobre flotación (*Ni flota ni se hunde*), así como el planteamiento que nos hicieron desde el simposio (*Floating and sinking: different approaches for research-based teaching learning sequences*) de ESERA 2021, argumentando que la densidad era un concepto más sencillo para Educación Primaria que las fuerzas, nos hicieron adaptar el modelo de fuerzas para la nueva SEA de Educación Primaria.
- Decisiones contextuales: la anterior decisión (abordar la flotación por fuerzas) nos permite usar menos *testing objects* que si lo hiciéramos por densidad (Estudio 2). Con el objetivo de no dispersar y concentrar la atención en un único *testing object* utilizamos una Coca Cola Light. Esto es debido a que, además de ser un objeto cotidiano y conocido por el alumnado, tiene la característica de que ni flota ni se hunde en agua. Así, y como puede deducirse, una de las principales diferencias con respecto a la SEA de formación inicial radica en el *testing object*: mientras que en la SEA de formación inicial utilizamos un bote de cristal con cierre hermético que se puede llenar o vaciar de distintos materiales (arena, agua, tornillos, etc.), en la de Educación Primaria optamos por un *testing object* completamente cerrado que no pueda ser manipulado y, de esta forma, evitar variaciones.
- Decisiones sobre la dimensión psicológica: pese a la multitud de concepciones alternativas que hay sobre flotación (Table 2) en nuestra SEA para Educación Primaria decidimos focalizarnos en *los objetos pesados se hunden mientras que los ligeros flotan*. Aparcamos para cursos superiores otras concepciones como *la identificación de masa con peso, volumen con capacidad, etc.*

- Decisiones didácticas: como se ha dicho en varios momentos de la Tesis Doctoral, uno de los intereses de Sensociencia es el diseño, la implementación y la evaluación de SEAs basadas en indagación y modelización, usando, para ello, los ciclos. Nuestra intención es diseñar SEAs que sean útiles para los maestros de Educación Primaria y Secundaria y poner de manifiesto que no se necesita mucho tiempo para implementarlas. Nuestra SEA de flotación para Educación Primaria, basada en indagación y modelización, puede ser implementada en 1-2 horas.
- Decisiones sobre la dimensión emocional: como hemos identificado en el Estudio 3 los momentos clave desde el punto de vista emocional (el diseño experimental para buscar pruebas y el uso del modelo para explicar y predecir sobre flotación), podemos refinar la SEA en función de las emociones que pretendamos provocar. Por ejemplo, al ser conscientes de que el momento en el que el bote o la Coca Cola Light ni flota ni se hunde produce asombro en el alumnado, decidimos retrasar esta comprobación hasta el momento en el que expresen sus ideas sobre qué hace que algo flote o se hunda. Así, conseguimos que los alumnos focalicen su atención única y exclusivamente en la identificación de sus propias ideas sobre flotación y asociamos el asombro con el fenómeno clave de la SEA.
- Decisiones ideológicas: en la SEA para futuros maestros utilizamos la fusión de los icebergs como aplicación de lo aprendido a un problema socioambiental sobre el calentamiento global. En la SEA para Educación Primaria hemos tomado la decisión de no plantearlo, pues ampliaría mucho la su duración. No obstante, sí proponemos una tarea en la que han de aplicar el modelo a una situación nueva que enlaza perfectamente con la concepción alternativa que estamos trabajando (objetos pesados se hunden y ligeros flotan): *¿Eres capaz de explicar cómo flota en el agua un transatlántico con todo lo que pesa?*

Una vez aclaradas cuáles han sido nuestras decisiones didácticas para el diseño de la SEA sobre flotación en el segundo ciclo de Educación Primaria, invitamos a los lectores a su visualización en el Annex VII. También mostramos las tareas que forman parte de la SEA junto a las fases de indagación, su objetivo didáctico, y el ciclo de emociones en la Figure 45.

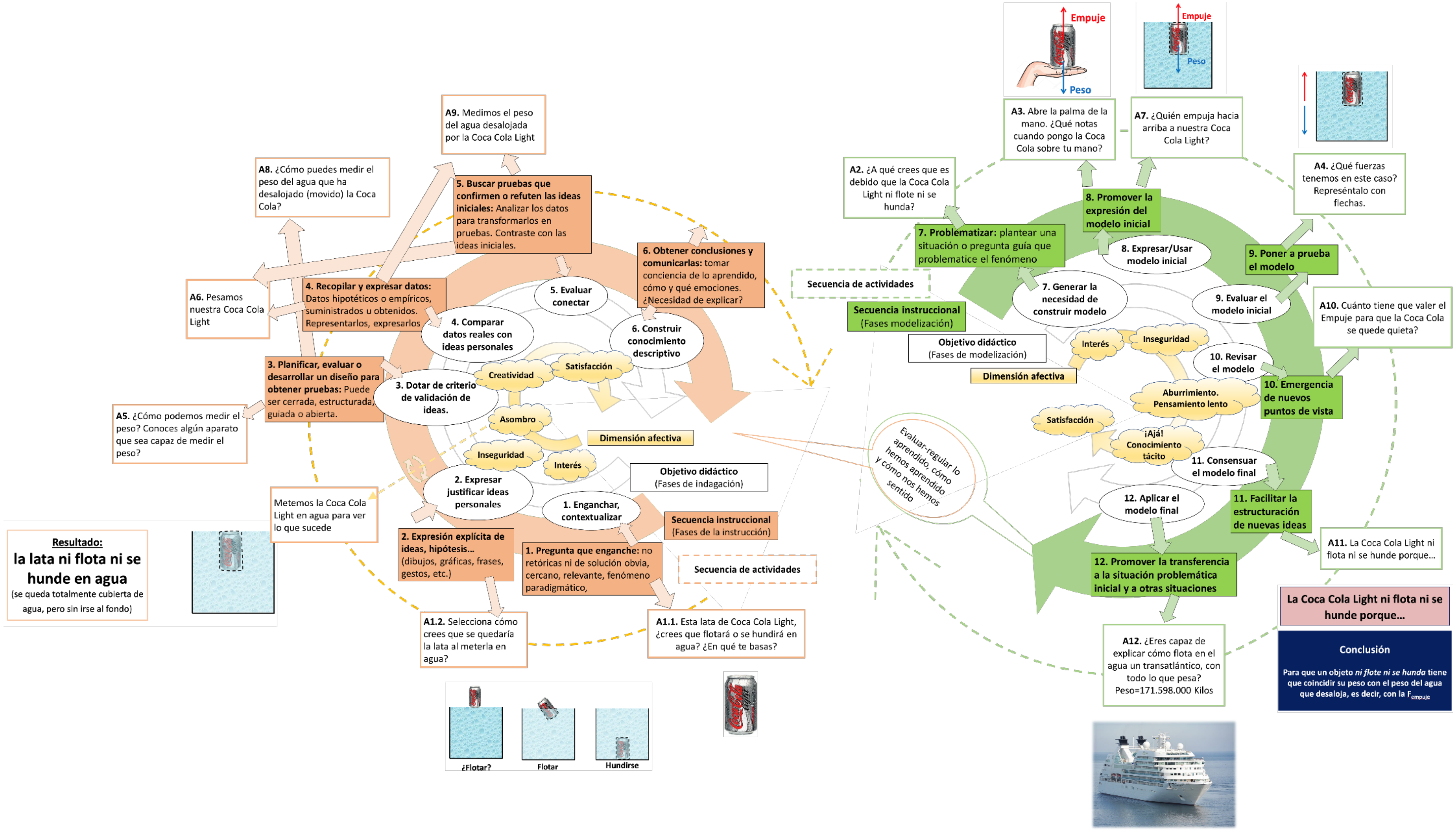


Figure 45. Secuencia sobre flotación para 2º ciclo de Educación Primaria

9. Líneas de investigación futuras

Toda Tesis Doctoral, como proceso iniciático de investigación, deja líneas abiertas de continuidad. Algunas de estas tareas pendientes surgen de la necesaria poda para el cierre del manuscrito. Por ejemplo, creemos necesario profundizar en la evaluación formativa de la SEA *Ni flota ni se hunde* a través del análisis de las grabaciones durante su implementación en la formación inicial de maestros en el curso 2017-2018. Se trataría de realizar un procedimiento similar al desarrollado en la Tesis Doctoral de Anna Garrido (Garrido Espeja, 2016): analizar la progresión de aprendizaje de los estudiantes y los detonantes producidos por las tareas, por los profesores o por el alumnado. Estos detonantes pueden triangularse con las respuestas abiertas al cuestionario de autorregulación (KPSI+emociones) que, por cuestiones de tiempo, tampoco hemos incluido en este documento.

Surgida del Estudio 3, planteamos como futura línea de investigación analizar si las tareas de la SEA *Ni flota ni se hunde* proporcionan objetivos claros, equilibrio reto-habilidad, etc. (aspectos vinculados a la teoría del flujo utilizada en el Estudio 3). Asimismo, también pretendemos analizar las interacciones que se produjeron entre alumno-alumno y profesor-alumno, ya que estos permitirán estudiar la retroalimentación dada o recibida. Este último elemento, la retroalimentación, se ha visto como un aspecto esencial para facilitar (desencadenar) o dificultar (inhibir) las experiencias de flujo y el clima emocional, lo que proporciona un marco relevante para nuestras futuras investigaciones.

Por último, de esta Tesis Doctoral surge el interés por el análisis de la práctica profesional de los docentes a la hora de diseñar/adaptar SEAs. Por ejemplo: qué lleva a un docente a elegir un enfoque conceptual (densidad/fuerzas) frente a otro; qué criterios utiliza para seleccionar una tarea u otra; o qué proceso de adaptación realiza para transferir a su aula las SEAs y tareas previamente buscadas. Esto supone una línea amplia de investigación en la que, desde Sensociencia, abordaremos tanto en cursos de formación de docentes en activo (Cortés-Galera et al., 2016; De Jong & van Driel, 2007) como en nuestros propios cursos de formación inicial de docentes.

Como hemos dicho en las conclusiones de la presente Tesis Doctoral, el enfoque metodológico realizado nos anima a replicarlo en nuevas propuestas educativas que, por su puesto, tendrán que ser nuevamente evaluadas. Teniendo esto en cuenta, nos animamos y animamos al resto de la comunidad investigadora a replicar esta misma estructura de investigación con diversos tópicos de ciencias en futuras tesis doctorales o proyectos de investigación.

10.Referencias

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Índice de Figuras

Índice de Tablas

Annex I. 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

En este anexo mostramos el artículo de investigación que recibe como título *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.*

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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

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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

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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 twofold: 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.

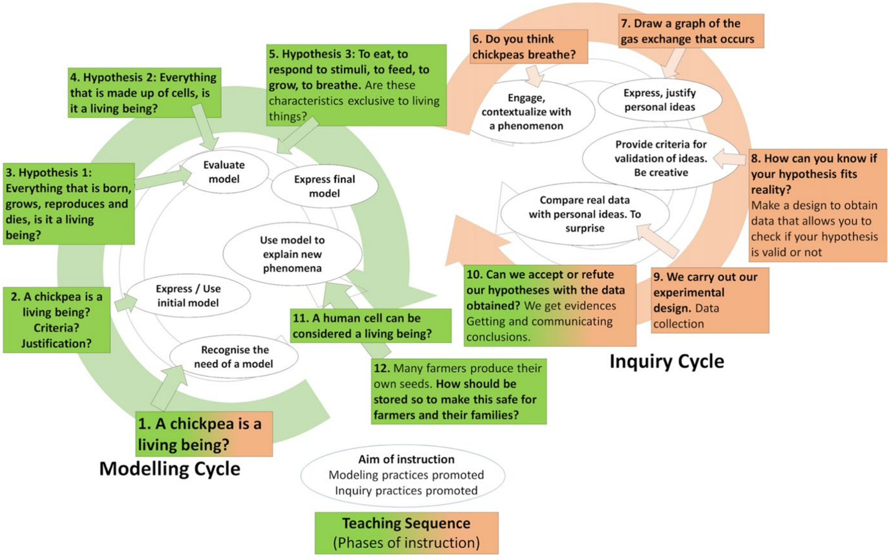

Fig. 2 Inquiry cycle (colour orange, adapted from Jiménez-Liso et al., 2019) connected to modelling cycle (colour green, adapted from Garrido & Couso, 2017) (Color figure online)

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

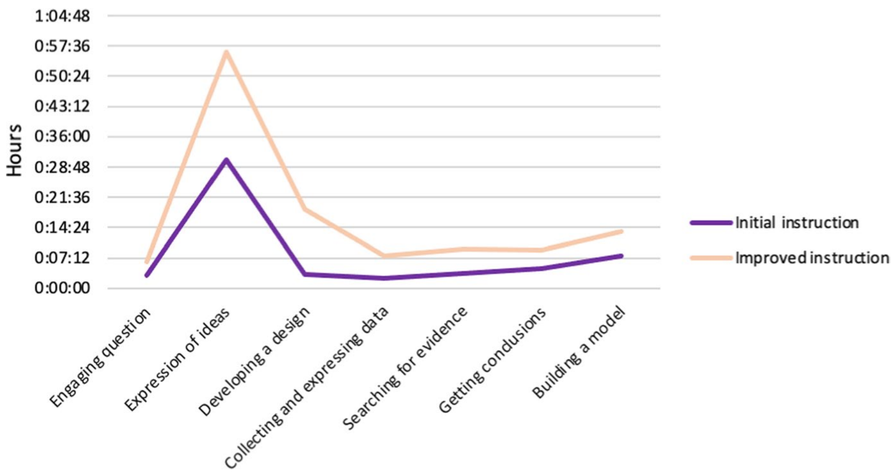

Fig. 3 Implementation times for each inquiry stage in initial (purple) and improved (orange) instructions, data from Table 3 (Microsoft Excel) (Color figure online)

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 ($N_{total\ messages} = 129$). 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 conclusions		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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Authors' contributions All authors whose names appear on the submission made substantial contributions to this paper. M.-R. Jimenez-Liso contributed to the study conception and design. Framework, material preparation, data collection, analysis, results and conclusions were performed and reviewed by F.-J. Castillo-Hernandez, M.-R.Jimenez-Liso and D. Couso. The first draft of the manuscript was written by F.-J. Castillo-Hernandez and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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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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Annex II. Protocolo de análisis Estudio 1

<table>
<tr><td></td><td colspan="3">Categories</td><td>Definition of categories
This category includes…</td></tr>
<tr><td rowspan="2">Objective</td><td colspan="3">Ideas diagnosis about floating and sinking phenomenon</td><td>those papers that only diagnose students' ideas, students' Piagetian operations, either through questionnaires, interviews, etc. and do not propose activities to improve the diagnosis.</td></tr>
<tr><td colspan="3">Teaching proposal about floating and sinking phenomenon</td><td>those papers in which the aim is to change the students' initial ideas by means of independent tasks or teaching-learning sequences.
These papers may include diagnostic ideas from the students (previous category) to support their proposal. As the categories are mutually exclusive, we will only include them here.</td></tr>
<tr><td rowspan="6">Concepts</td><td rowspan="6">Forces</td><td rowspan="3">Buoyant force</td><td>Qualitative</td><td rowspan="3">those papers that cite buoyant force as a force with vertical upward direction.
Qualitative: this refers to papers in which this content is worked on without any type of mathematical formula.
Quantitative: this refers to papers in which this content is worked with a mathematical formula.
Not specified: this refers to papers that do not specify how this content is to be worked.
Footnote[4]</td></tr>
<tr><td>Quantitative (formula)</td></tr>
<tr><td>Not specified</td></tr>
<tr><td rowspan="3">Weight force</td><td>Qualitative</td><td rowspan="3">those papers that cite weight as a vertical and downward force.</td></tr>
<tr><td>Quantitative (formula)</td></tr>
<tr><td>Not specified</td></tr>
</table>

[4] In order not to repeat exactly the same thing in the rest of the categories, the subcategories *qualitative, quantitative* and *not specified* will not be repeated here since they present the same definition.

		Equilibrium of forces	Qualitative Quantitative (formula) Not specified	those papers that cite the balance between buoyant and weight force with the same value and, therefore, counteract each other.
		Pressure	Specified	those papers in which, in order to explain buoyancy, pressure is taken into account.
			Not specified	those papers that cite pressure but do not specify what/how they are working on it.
		Surface tension	Specified	those papers in which, in order to explain flotation, surface tension is taken into account.
			Not specified	those papers that cite surface tension but do not specify what/how they are working on it.
		It does not specify which forces work	those papers that cite the forces but do not specify what/how they are working them. In these papers they exclusively specify that they will work the buoyancy in terms of forces but do not explain how.	
	Density	Mass	Qualitative Quantitative (formula) Not specified	those papers in which flotation is explained in terms of density and, in addition, mass is specifically worked out.
		Volume	Qualitative Quantitative (formula) Not specified	those papers in which buoyancy is explained in terms of density and, in addition, volume is specifically worked on. We would also include those papers of liquid displacement after introducing an object to obtain volume (Archimedes' Principle).
		Relationship between mass and volume	Qualitative Quantitative (formula) Not specified	those papers in which the relationship between mass and volume is specified, which gives rise to the definition of density.
		Relative density	Qualitative Quantitative (formula) Not specified	those papers in which, in order to explain buoyancy, explicitly state that there is a comparison of densities of the object and the fluid in which it is found.

<table>
<tr><td rowspan="2"></td><td colspan="2" rowspan="2"></td><td colspan="2" rowspan="2">Property of matter</td><td>Specified</td><td>those papers in which density as a property of materials is discussed.</td></tr>
<tr><td>Not specified</td><td>those papers that do not specify what they are working on in terms of density. In these papers they only specify that flotation will be worked on in terms of density but do not explain how.</td></tr>
<tr><td rowspan="8">Testing objects</td><td rowspan="6">Testing objects in liquids</td><td rowspan="2">Classroom testing objects</td><td colspan="2">Cube/Sphere</td><td colspan="2">those situations in which cubes/spheres are introduced into a liquid.</td></tr>
<tr><td colspan="2">Liquids</td><td colspan="2">those situations in which different liquids are introduced into the same container.</td></tr>
<tr><td rowspan="5">Daily testing objects</td><td rowspan="2">Testing objects that simulate real ones</td><td>Boat</td><td colspan="2">those situations in which a boat (model or material) is introduced into a liquid.</td></tr>
<tr><td>Submarine</td><td colspan="2">those situations in which a submarine is introduced into a liquid.</td></tr>
<tr><td colspan="2">Coca Cola</td><td colspan="2">those situations in which cans of Coca Cola are introduced into a liquid.</td></tr>
<tr><td colspan="2">Others</td><td colspan="2">those situations in which different objects are introduced (either real or figurative), such as candles, life jackets, divers, toy crocodiles, etc.</td></tr>
<tr><td>Testing objects in gas</td><td colspan="2">Balloons</td><td colspan="2">those situations in which balloons are introduced into a given fluid.</td></tr>
<tr><td colspan="4">Testing object is not specified</td><td colspan="2">those papers that do not specify which testing objects they are using.</td></tr>
<tr><td>Teaching approach</td><td colspan="2">Sequences of activities</td><td colspan="2">POE</td><td colspan="2">those sequences of activities in which the authors acknowledge following the POE teaching approach or those in which the students have to predict (P) what is going to happen regarding a certain flotation phenomenon, then observe (O) what actually happens and, finally, explain (E) (the students or the teachers) why it has happened.</td></tr>
</table>

		Guided discovery	those sequences of activities in which the authors acknowledge following the guided discovery teaching approach or those in which the activities promote it, i.e., students observe the phenomenon (without expressing their ideas or predictions), execute an experimental design (generally elaborated by the teacher, recipe type) and, finally, infer/relate/generalize. Inductive didactic model.
		Conceptual change	those sequences of activities in which the authors acknowledge following the teaching approach of conceptual change or those in which the activities promote it, i.e., after diagnosing the students' previous ideas, they put them in conflict through mental or manipulative experiments.
		Inquiry	those sequences of activities in which the authors recognize to follow inquiry.
		Modeling	those sequences of activities in which the authors acknowledge following modeling.
		Argumentation	those sequences of activities in which the authors recognize that they are following argumentation.
		Direct instruction experiment	those sequences of activities that are characterized by showing students what steps they have to follow concretely to carry out an experiment.
		Not specified by authors	those papers in which the authors do not clearly state what teaching strategy or approach they are employing.
	Activities without sequence		those papers in which the authors present activities without sequencing. They are individual activities to deal with the phenomenon of floating and sinking.
	With evaluation of impact	Conceptual contents change	those sequences that evaluate their impact in terms of the evolution of the learner's ideas.

Evaluation of the sequences of activities		Students satisfaction	those sequences that evaluate their impact in terms of student satisfaction.
		Epistemological contents change	those sequences that evaluate their impact in terms of the change in students' ideas about the epistemology of science.
	Without evaluation of impact	those sequences that have not evaluated their impact.	

Annex II. Protocolo de análisis Estudio 1

Annex III. Protocolo de análisis Estudio 2

Variables a analizar en la SEA	Cómo obtenemos las categorías y cómo las identificamos en las SEAs
Concepciones alternativas	**Obtención de las categorías:** Las concepciones alternativas han sido previamente identificadas en (Estudio 1). Pulsar enlace para visualizarlas. **Proceso para identificar las categorías:** Identificación deductiva de las concepciones alternativas que se abordan en las secuencias de enseñanza-aprendizaje (SEA). Para la identificación, leemos cada una de las tareas propuestas en las SEAs e interpretamos qué concepciones alternativas se han abordado.
Tratamiento conceptual	**Obtención de las categorías:** Dos tipos de categorías: modelos[5] y conceptos asociados a estos. Ambas categorías han sido previamente identificadas (Estudio 1): - Modelo 1. Fuerzas. Los conceptos asociados son: o Fuerza empuje o Fuerza peso o Equilibrio de fuerzas o Presión o Tensión superficial - Modelo 2. Densidad. Los conceptos asociados son: o Masa o Volumen o Relación entre masa y volumen (concepto de densidad) o Densidad relativa o Densidad como propiedad de la materia. Además de estos conceptos de forma inductiva han aparecido otros: - Cantidad de fluido - Diámetro de un recipiente - Carga límite - Principio de Arquímedes - Interacción de fuerzas - Del desequilibrio al equilibrio

[5] Entendemos por modelo las grandes ideas de la ciencia que permiten describir, explicar y predecir los fenómeno de la naturaleza (Couso, 2020)

	- Flotación de objetos - Reconciliación fuerzas/densidad **Proceso para identificar las categorías:** Identificación inductiva-deductiva de los conceptos que se abordan en las SEAs: se trata de un proceso inductivo-deductivo debido a que, pese a que previamente se identificaron los conceptos (Estudio 1), pueden surgir nuevos como consecuencia del análisis de las SEAs. En este último caso, los identificamos de forma inductiva y lo añadimos a nuestro protocolo de análisis. La identificación puede llevarse a cabo mediante dos vías: - Cuando los conceptos no son indicados por los autores de la SEA, procedemos a su interpretación mediante la lectura de las tareas. - Cuando los conceptos son indicados por los autores de la SEA lo vinculamos a uno (o varios) de los conceptos previamente identificados.
Testing objects	**Obtención de las categorías:** Tres tipos de categorías: 1) tipo de testing object; 2) el testing object concreto; y 3) si es real o es una simulación. El tipo de testing object ha sido previamente identificado en el estudio 1 de la presente Tesis Doctoral: - Daily testing objects: hacen referencia a objetos de la vida cotidiana traídos al aula para abordar el fenómeno de flotación. - Classroom testing objects: hacen referencia a objetos específicamente diseñados para abordar el fenómeno de flotación. **Proceso para identificar las categorías:** Identificación inductiva-deductiva de los testing objects utilizados en las SEAs: se trata de un proceso inductivo-deductivo debido a que, en primer lugar, identificamos los testing objects concretos de cada una de las SEAs de forma inductiva y, en segundo lugar, los categorizamos según el tipo de testing object: *Classroom testing objects* o *Daily testing objects*.
Número de testing objects	**Obtención de categorías:** Las categorías se han identificado de forma inductiva: - SEAs que no presentan ningún testing object o son una simulación digital - SEAs con un número de testing objects entre 1-5 - SEAs con un número de testing objects entre 5-10 - SEAs con un número de testing objects superior a 10 **Proceso para identificar las categorías:** Identificación inductiva: recuento de testing objects utilizados en cada SEA y su posterior asociación a las categorías previamente definidas.
Número de tareas	**Obtención de categorías:** Las categorías se han identificado de forma inductiva: - SEAs con un número de tareas entre 0-5 - SEAs con un número de tareas entre 6-11 - SEAs con un número de tareas entre 12-17

	- SEAs con un número de tareas superior a 18 **Proceso para identificar las categorías:** Identificación inductiva: recuento de tareas realizadas en cada SEA y su posterior asociación a las categorías previamente definidas.
Enfoque de enseñanza	**Obtención de las categorías:** Dos tipos de categorías: enfoque y las fases asociadas al enfoque. Ambas categorías han sido previamente identificadas (Estudio 1): - Enfoque 1. Indagación. Fases asociadas: o pregunta que engancha o expresión explícita de ideas, hipótesis… o planificar, evaluar o desarrollar un diseño para obtener pruebas o recopilar y expresar datos o buscar pruebas que confirmen o refuten las ideas iniciales o obtener conclusiones descriptivas y comunicarlas - Enfoque 2. Modelización. Fases asociadas: o reconocer la necesidad de un modelo o expresar/usar el modelo inicial o evaluar el modelo o revisar el modelo o consensuar un modelo final o aplicar el modelo final **Proceso para identificar los conceptos:** Identificación deductiva[6] del enfoque de enseñanza y sus fases en las SEAs. Para la identificación, en primer lugar, leemos la SEA al completo y la categorizamos como indagación o modelización y, en segundo lugar, leemos cada una de las tareas e interpretamos con qué fase del enfoque de enseñanza se corresponde.

Annex III. Protocolo de análisis Estudio 2

[6] Para la identificación de las fases de ambos enfoques utilizamos el marco teórico de la presente Tesis Doctoral (Figure 2)

Annex IV. Autores de las SEAs sobre flotación

Debido a que las SEAs sobre flotación han sido diseñadas por otros autores, hemos decidido no mostrarlas en su versión completa. Para ello, proporcionamos los correos electrónicos de los autores y que sean ellos mismos los que decidan qué y con quién compartir. Como excepción encontramos la SEA *Sink or float,* que, al haber sido financiada a través de un proyecto europeo, es de dominio público. Procedemos, entonces, a indicar los contactos de los autores y el enlace web para descargar la SEA *Sink or float:*

- *Sink or float*: enlace
- *Exploring flotation of objects in liquids*: arodrigues@ua.pt (Ana V. Rodrigues)
- *Density of materials in floating/sinking phenomena*: tzoupidis@gmail.com (Tasos Zoupidis)
- *¿Por qué flotan algunas cosas?*: digna.couso@uab.cat (Digna Couso)
- *Ni flota ni se hunde*: fch123@ual.es (Francisco José Castillo Hernández)

Annex V. Learning and self-reflection task

Learning and emotional self-reflection task

1 I do not know anything **2** I know a little **3** I know it well **4** I know it very well **5** I can explain it to a friend

BEFORE TLS **1 2 3 4 5**	**Knowledge about…**	**AFTER TLS** **1 2 3 4 5**	Point out the **emotion or emotions** felt while working on that knowledge and briefly explain **the cause** of that feeling
	Difference between volume and capacity. Units, measurement procedure and estimates.		☐Rejection ☐Concentration ☐Insecurity ☐Interest ☐Boredom ☐Confidence ☐Satisfaction ☐Dissatisfaction ☐Embarrassment **Because…**
	Difference between mass and weight. Units, measurement procedure and estimates. Relationship between mass and weight.		☐Rejection ☐Concentration ☐Insecurity ☐Interest ☐Boredom ☐Confidence ☐Satisfaction ☐Dissatisfaction ☐Embarrassment **Because…**
	Justify your answer and design the search for evidence to answer: *how much sand should be put into the jar so that it does not float or sink?*		☐Rejection ☐Concentration ☐Insecurity ☐Interest ☐Boredom ☐Confidence ☐Satisfaction ☐Dissatisfaction ☐Embarrassment **Because…**
	Phantom object model to determine the value of the buoyant force exerted by a fluid on an object.		☐Rejection ☐Concentration ☐Insecurity ☐Interest ☐Boredom ☐Confidence ☐Satisfaction ☐Dissatisfaction ☐Embarrassment **Because…**
	Use of the (weight-buoyant) model to explain the floating or sinking of objects (*can, submarine, balloon, diver…*) immersed in a fluid.		☐Rejection ☐Concentration ☐Insecurity ☐Interest ☐Boredom ☐Confidence ☐Satisfaction ☐Dissatisfaction ☐Embarrassment **Because…**
	Physical meaning of density. Use of the (weight-buoyant) model to justify that the comparison between density of the object and the fluid explains whether it floats or sinks.		☐Rejection ☐Concentration ☐Insecurity ☐Interest ☐Boredom ☐Confidence ☐Satisfaction ☐Dissatisfaction ☐Embarrassment **Because…**
	Using the (weight-buoyant) model to predict how much an object floating in a liquid sinks		☐Rejection ☐Concentration ☐Insecurity ☐Interest ☐Boredom ☐Confidence ☐Satisfaction ☐Dissatisfaction ☐Embarrassment **Because…**

Annex V. Learning and emotional self-reflection task

Annex VI. Mapas conceptuales

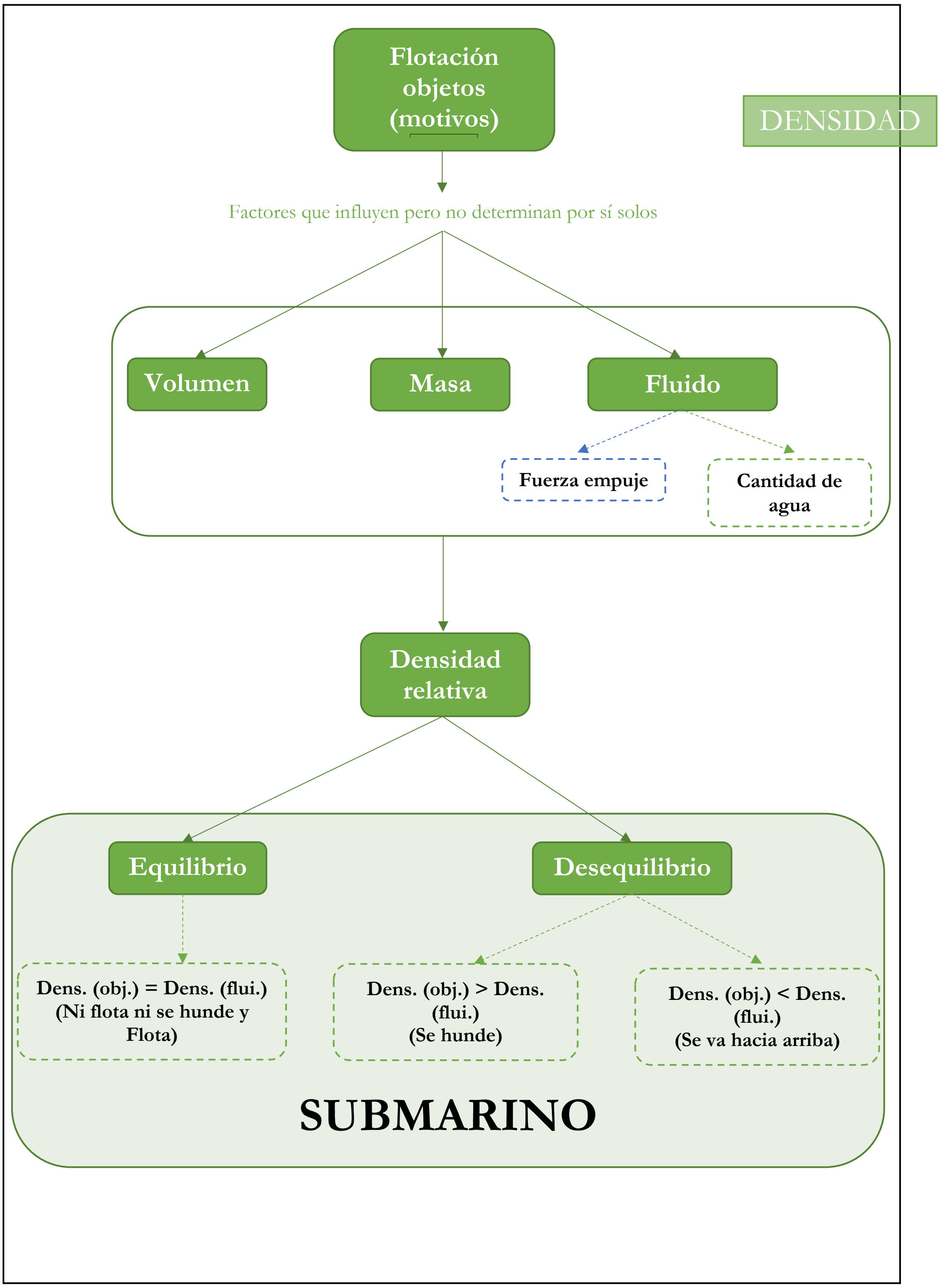


Figure 46. *Sink or Float*

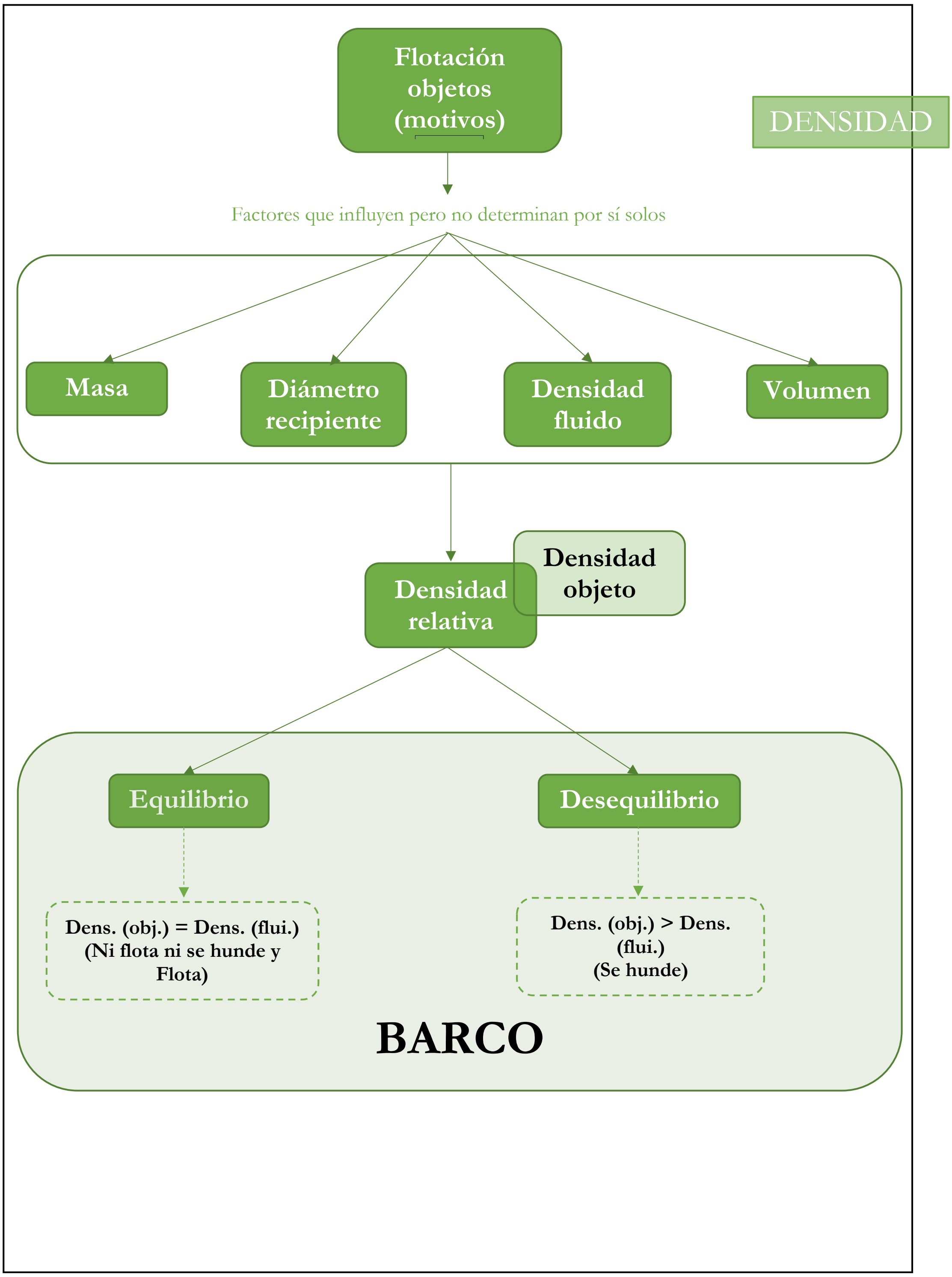


Figure 47. *Density of materials in floating/ sinking phenomena*

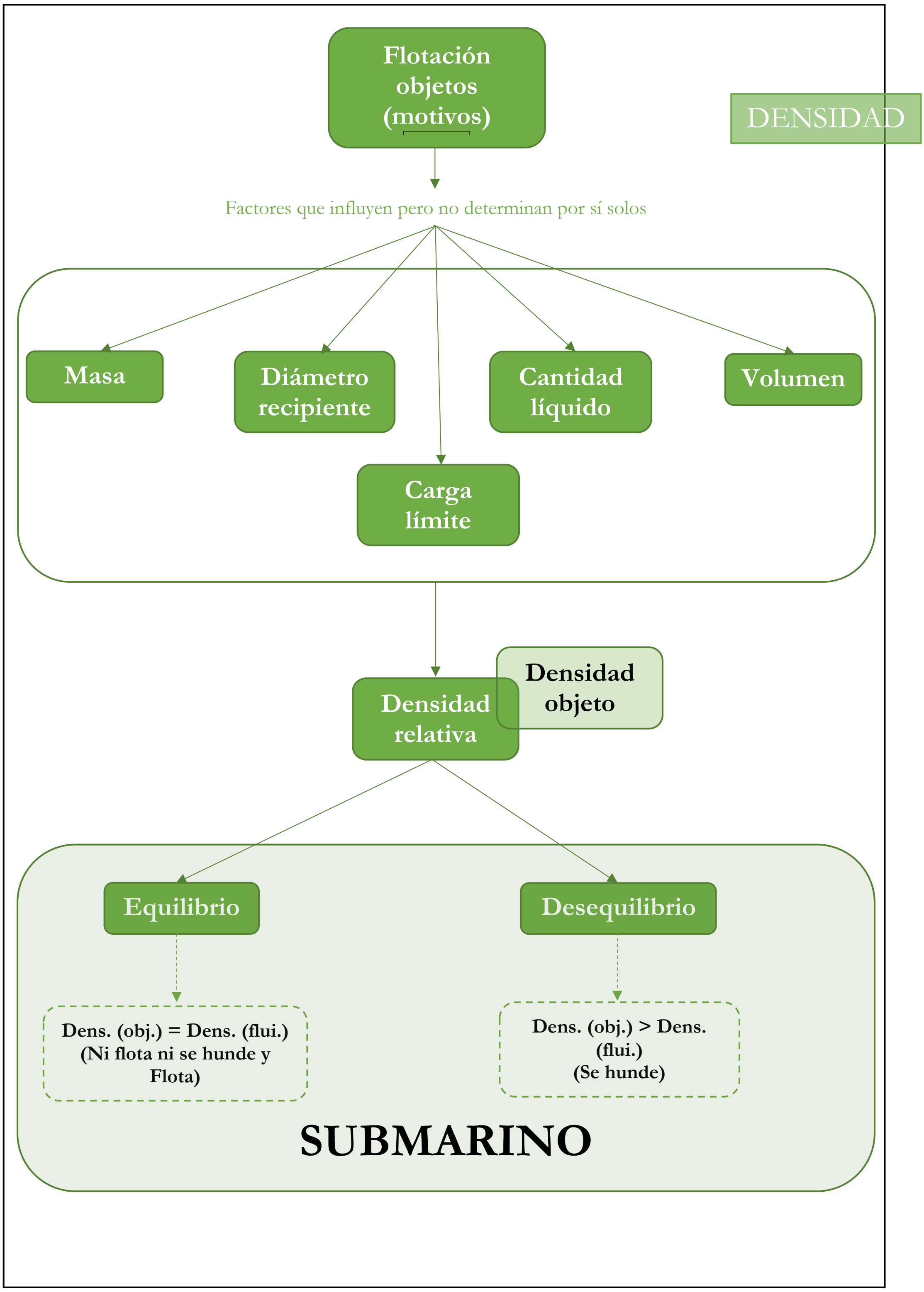


Figure 48. *Exploring flotation of objects in liquids*

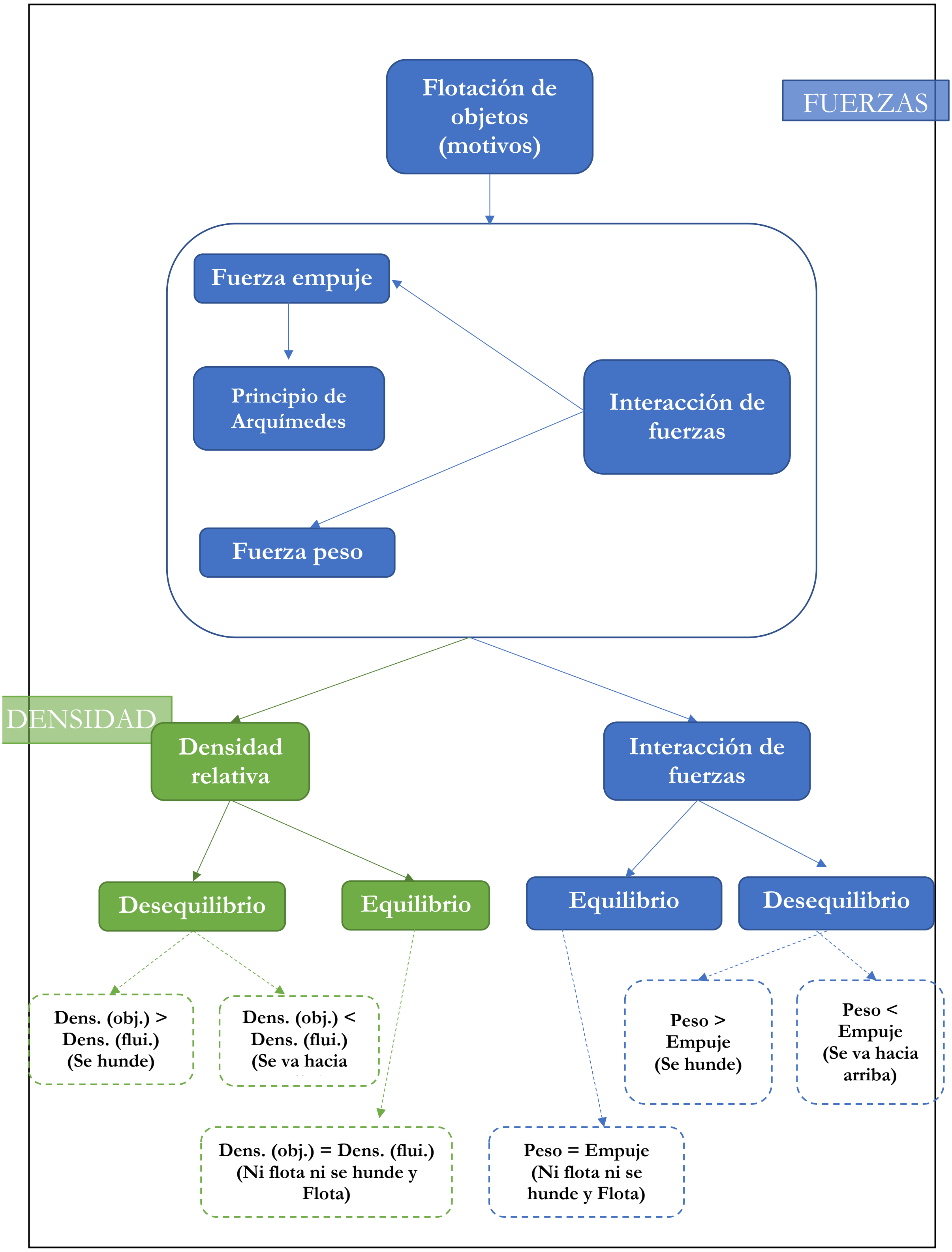


Figure 49. *¿Por qué flotan algunas cosas?*

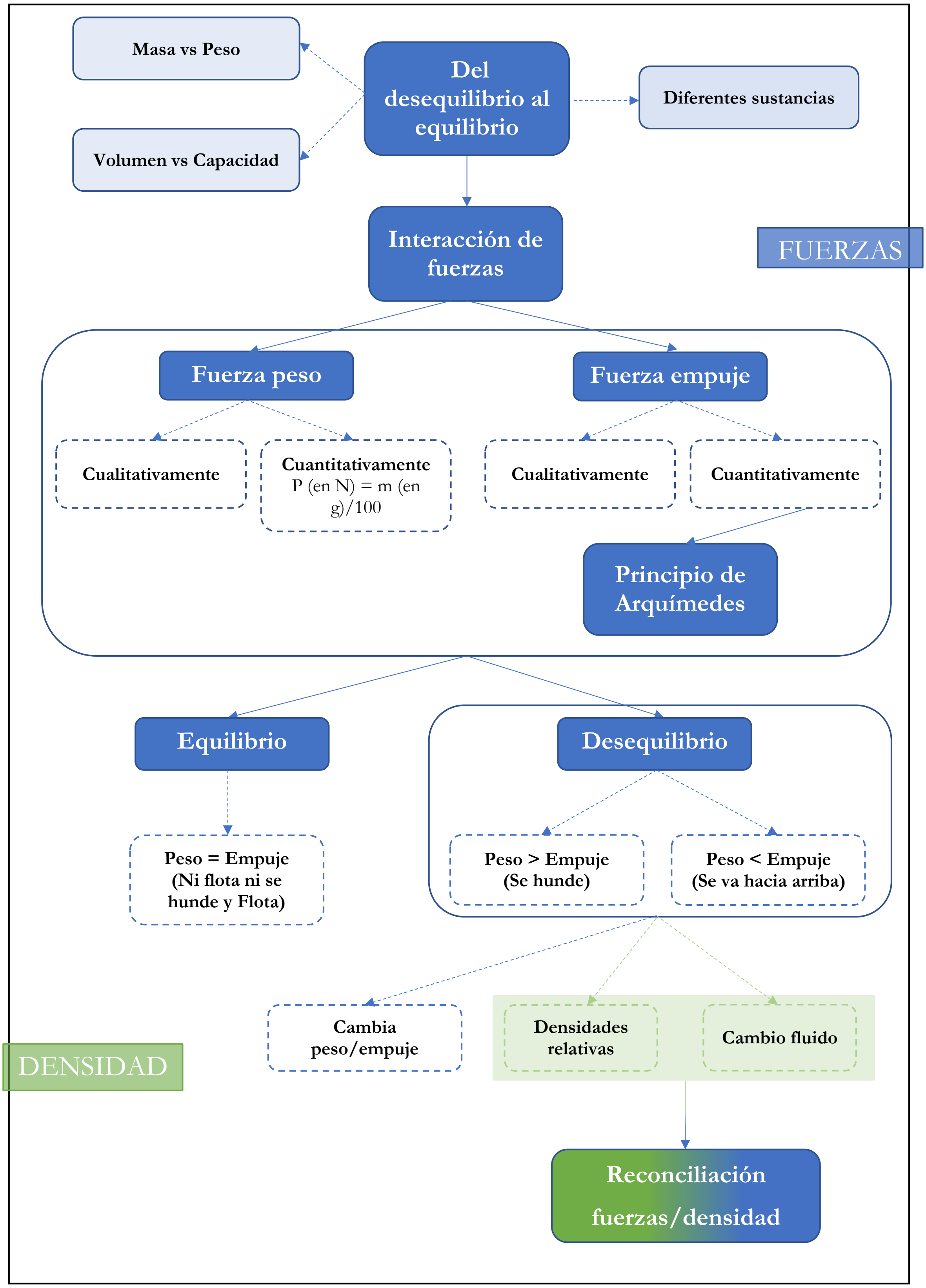


Figure 50. *Ni flota ni se hunde*

Annex VII. Ni flota ni se hunde: ¿Es possible iniciar el modelo de fuerzas en Educación Primaria?

En este anexo mostramos el artículo de investigación que recibe como título *Ni flota ni se hunde: ¿Es posible iniciar el modelo de fuerzas en Educación Primaria?*

Ni flota ni se hunde

¿Es posible iniciar el modelo de fuerzas en educación primaria?

Francisco José Castillo Hernández, María Rut Jiménez Liso, María Martínez Chico, Rafael López-Gay Lucio-Villegas

En este artículo presentamos una secuencia sobre flotación para el segundo ciclo de educación primaria. Para el diseño nos hemos guiado por el enfoque de enseñanza basado en indagación, modelización y argumentación, y en el modelo científico escolar de fuerzas. La secuencia ha sido implementada y discutida con maestros y maestras en actividad y con su alumnado de 4.º de educación primaria, a fin de evaluarla e introducir los cambios necesarios.

PALABRAS CLAVE

- física
- flotación de objetos
- prácticas científicas
- modelo de fuerzas
- indagación
- modelización
- argumentación

Cuando vemos a un niño o niña sujetando un globo porque este se va hacia arriba, cuando vamos a la playa y vemos un barco en la superficie del agua, o cuando jugábamos de pequeños en la bañera y veíamos que algunos juguetes flotaban y otros se hundían: todas estas situaciones responden a un mismo fenómeno, la flotación. Está claro que hemos tenido experiencias con estos fenómenos, pero ¿podríamos afirmar que la población es capaz de explicar científicamente y hacer predicciones sobre la flotación?

¿Podríamos afirmar que la población es capaz de explicar científicamente y hacer predicciones sobre la flotación?

Según la literatura didáctica, las explicaciones personales suelen hacer referencia a que un objeto flota porque pesa poco, o se hunde

> **Diseñamos secuencias de actividades con las que construir explicaciones más sofisticadas, más explicativas y predictivas**

porque pesa mucho, también afirman que va a depender de su forma, su posición, de qué material está hecho, su densidad o la cantidad de líquido en la que se sumerja. Parece entonces que estas concepciones alternativas perduran tras la escolaridad. En SensoCiencia diseñamos secuencias de actividades con las que construir explicaciones más sofisticadas, más explicativas y predictivas.

En el presente artículo mostramos el diseño de una secuencia de actividades para 4.º de educación primaria, de dos horas de duración, en torno al fenómeno de la flotación. Antes de eso, expondremos nuestras decisiones sobre el modelo científico escolar y el enfoque de enseñanza.

¿QUÉ MODELO CIENTÍFICO ESCOLAR ENSEÑAR? ¿CÓMO ENSEÑARLO?

Nuestro objetivo como docentes es que los alumnos aprendan a construir las grandes ideas de la ciencia (Harlen, 2015) para describir, explicar, predecir e intervenir en los fenómenos de la naturaleza. En este sentido, proponemos una secuencia de actividades basada en el modelo científico de fuerzas, teniendo en cuenta que un modelo no se aprende de una vez para siempre, sino que tiene que construirse de forma progresiva a lo largo de la escolaridad.

Hemos seleccionado un conjunto de ideas –conscientes de su validez limitada– que constituyen el modelo científico de fuerzas que queremos desarrollar en educación primaria:

- Las fuerzas están asociadas a percepciones y la experiencia inmediata: empujar, sostener, etc. Esta primera conceptualización todavía está lejos del concepto abstracto de fuerza como medida de una interacción.
- Cada fuerza es ejercida por algo o alguien que no es el objeto; el objeto no se aplica fuerza a sí mismo, por lo que hay que especificar. En el caso de la fuerza peso, siempre presente en nuestro entorno cotidiano, es difícil probar y aceptar que es ejercida por la Tierra, y se confunde con una propiedad del objeto. Conscientes de este obstáculo, no nos detendremos especialmente en su superación, tan solo indicaremos que es la Tierra la que empuja a los objetos hacia el suelo.
- Las fuerzas pueden representarse mediante flechas que indican su dirección y sentido. Utilizaremos como aparato de medida la balanza, que indica la fuerza que ejerce sobre el objeto y expresa el resultado en gramos. Sin entrar a discutir la relación entre esa medida y la masa del objeto –una magnitud todavía desconocida para los estudiantes–, expresaremos el valor de las fuerzas en gramos, lo que equivale a usar el submúltiplo del Sistema Técnico de Unidades gramo fuerza (pondio).
- Cuando un objeto se encuentra en reposo, las fuerzas que actúan sobre él se contrarrestan. Por nuestra parte, solo trabajaremos el equilibrio estático.

> **El modelo científico de fuerzas tiene que construirse de forma progresiva a lo largo de la escolaridad**

> **Las fuerzas están asociadas a percepciones y la experiencia inmediata: empujar, sostener, etc.**

Para la enseñanza del modelo, adoptamos un enfoque de indagación, modelización y argumentación, organizando la enseñanza a partir de actividades propias de la ciencia: expresar y discutir ideas, buscar pruebas para validar esas ideas, construir y evaluar modelos o ideas que vayan más allá de lo meramente perceptible (Couso y otros, 2020).

SECUENCIA DE ACTIVIDADES COMENTADA: NI FLOTA NI SE HUNDE

Esta secuencia de actividades ha sido implementada, discutida y mejorada con un grupo de maestras del CEIP Virgen del Mar (Almería) y con su alumnado de 4.º de educación primaria. A continuación, mostramos el enunciado junto a un breve comentario de cada una de las actividades.

> A1. ¿Crees que esta lata de Coca-Cola Light flotará o se hundirá en agua? ¿En qué te basas? Dibuja cómo quedaría la lata en el agua.

Algunos estudiantes piensan que los objetos que flotan se encuentran apoyados en la superficie: al discutir los dibujos, acuerdan que flota si hay una parte del objeto que queda sobre la superficie y se hunde cuando se va hasta el fondo del recipiente. Los niños y las niñas expresan y discuten sus ideas sobre las razones por las que un objeto flota o se hunde. Recogemos sus ideas en la pizarra y nos centramos en las que hacen referencia al peso. El resto de las respuestas («tiene gases», «está hecha de metal», «depende del tamaño del recipiente») las guardamos para tratarlas en A8.

A continuación, introducimos la lata de cola *light* en agua, mostrando que queda totalmente cubierta pero no se va al fondo del recipiente: ni flota ni se hunde. Hacemos esta comprobación primero con el recipiente completamente lleno, recogiendo el agua que desaloja en una bandeja, y después con el recipiente parcialmente lleno, reconociendo que lo que hace el agua desalojada es subir el nivel. También lo hacemos en recipientes de diferente tamaño y con distinta cantidad de agua.

A2. Antes de medir, comparamos. Cierra los ojos y abre la palma de la mano: ¿qué objeto pesa más?

Para relacionar el peso con la percepción, proponemos al alumnado que coloquen las palmas de las dos manos hacia arriba y en cada una de ellas colocamos distintos botes opacos que hemos preparado usando gravilla y virutas de corcho (imagen 1). Los objetos son una caja de galletas (flotará), un termo (flotará), una lata de Coca-Cola Light (ni flotará ni se hundirá), y un bote pequeño (se hundirá).

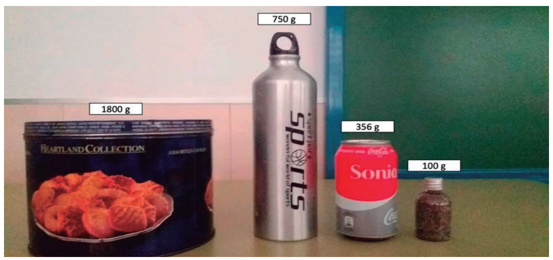


Imagen 1. Objetos usados

El alumnado debe ordenar los objetos según su peso percibido con la palma de la mano. Durante la actividad, a veces ejercemos una pequeña fuerza adicional sobre el objeto para que nos informen de su percepción.

Reconocemos que el peso empuja a los objetos hacia abajo y la palma de la mano hacia arriba para contrarrestarlo, y por eso se queda «quieto» en nuestra mano. Nuestra percepción se refiere directamente al empuje e indirectamente al peso del objeto (es el mismo valor).

Al final, les ayudamos a representar mediante flechas cada una de las fuerzas. Llevamos flechas de distinto color y tamaño fabricadas con goma eva, y después lo pasamos a flechas dibujadas en la pizarra.

A3. Elige las flechas que creas que representan el peso y el empuje sobre la lata en cada una de estas tres situaciones (imagen 2).

Incluimos una situación en la que no hay equilibrio de fuerzas para justificar el movimiento, insistiendo en que cada vez se mueve más rápido. Además, introducimos la mesa y la balanza para reconocer la existencia del empuje, aunque en este caso no haya percepción.

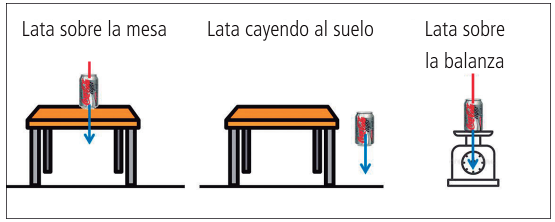


Imagen 2. Distintas situaciones para aplicar el modelo de fuerzas introducido

Al final de la actividad, encendemos la balanza y comentamos que la pantalla indica cuánto vale la fuerza con la que empuja al objeto hacia arriba.

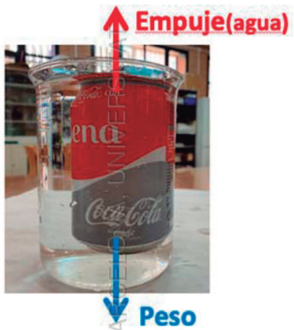
De ahí podemos deducir el valor del peso del objeto. Los estudiantes miden entonces el peso de los diferentes objetos, representando mediante flechas cada situación (imagen 3).

Imagen 3. Fuerzas que interactúan (y su valor) al situar la cola *light* sobre una balanza

Introducimos la lata de cola *light* en agua, mostrando que queda totalmente cubierta pero no se va al fondo del recipiente: ni flota ni se hunde

A4. Representa las fuerzas que empujan la lata e indica su valor (figura 4).

En este caso, reconocen que la lata está en equilibrio porque el agua empuja hacia arriba con una fuerza igual al peso del objeto.



Situación	Peso	Empuje del agua
Cola *Light*. Ni flota ni se hunde	356 g	356 g

Imagen 4. Representación cualitativa y cuantitativa de la fuerza, el peso y el empuje

A5. ¿Qué les va a suceder a los demás objetos cuando sean colocados en un recipiente con agua? Dibuja y explica tu predicción. Luego comprueba y representa mediante flechas las fuerzas que actúan, e indica su valor.

De nuevo se retoma la hipótesis inicial según la cual era el peso del objeto el que determinaba si se hundía o flotaba. El alumnado comprueba, para su sorpresa, que los objetos que pesan más (el termo y la lata de galletas) flotan, mientras que el que pesa menos (el bote pequeño) se hunde. En términos de fuerzas, el agua empuja al termo o a la lata (en equilibrio) con una fuerza igual al peso que ya han medido, mientras que empuja al bote pequeño (que está cayendo) con una fuerza menor que el peso.

Al final de la actividad les pedimos que empujen hacia abajo con el dedo la lata de galletas, que está flotando; en ese momento perciben que cada vez les cuesta más (el agua empuja más) y comprueban que la lata desaloja más agua (Garrido Espeja, 2016). Repetimos la misma operación con un globo. Concluimos que el valor del empuje parece estar relacionado con el agua que desaloja.

A6. ¿Cómo podemos medir cuánto pesa el agua que desaloja la lata?

Los alumnos presentan y discuten sus diseños. Al final, acordamos colocar el vaso sobre una bandeja, llenarlo hasta el borde, introducir la lata con cuidado y recoger toda el agua desalojada.

Imagen 5. Procedimiento para medir el agua desplazada por la lata

Después de evaluar los diseños, lo llevamos a cabo para anotar los resultados en la tabla que ya habían comenzado a hacer en A4, añadiendo ahora el peso del agua desalojada.

Es muy frecuente que el resultado esperado por nosotros (igual al peso de la lata) lo obtengan muy pocos grupos. Reconocemos las fuentes de error y les mostramos un procedimiento más sofisticado (imagen 5) con el que sí obtenemos el resultado deseado.

Concluimos: según este resultado, el empuje es igual al peso del agua desalojada. ¿Ocurre siempre lo mismo?

A7. ¿Cuánto pesará el agua desalojada por el bote pequeño y por el termo?

Los resultados obtenidos nos permiten concluir que, cuando el objeto está hundido o flotando, el agua lo empuja hacia arriba con una fuerza que es igual al peso del agua que ha desalojado.

> A8. Una lata de cola «normal», ¿flotará o se hundirá? ¿En qué te basas?

Hasta ahora nos hemos centrado en las hipótesis relacionadas con el peso que se expresaron en A1. Ahora nos centramos en las otras ideas, que están relacionadas, por ejemplo, con los materiales, la forma, etcétera. Así, usamos el hecho de que una lata similar de cola normal se hunde en agua para discutir que ambas latas contienen gas, están hechas de metal, contienen líquido y presentan la misma forma, por lo que esas variables por sí solas no pueden justificar que la lata flote o se hunda. Aplicando el modelo de fuerzas que hemos construido, el alumnado sabe que tiene que comparar el peso de la lata y el peso del agua desalojada.

> A9. Recapitulamos: ¿qué hemos aprendido?

Proponemos esta actividad de autorregulación para que el alumnado tome conciencia de los aprendizajes que han incorporado tras una sesión de dos horas y para que surjan nuevas preguntas relacionadas con el tema. Un ejemplo es la que proponemos a continuación.

> A10. Lo que hemos aprendido nos sirve para explicar las razones que hacen que el barco *Harmony of the Seas* flote pese a que tiene capacidad para 5.500 pasajeros y un peso de 227.000.000 kg. ¿Cómo puedes explicar que flote?

La flotación de los barcos es el fenómeno por excelencia por el que se preguntan los alumnos. En esta actividad podemos plantear cómo explicarlo comparando el peso del barco con el del agua desalojada y dirigiendo la atención a la parte sumergida del barco.

Con la secuencia descrita, ayudamos a explicar y a predecir si un objeto se hunde o flota comparando el peso del objeto con el peso del agua que desaloja

A MODO DE CONCLUSIÓN

El fenómeno de flotación, presente en el currículo escolar desde la educación infantil, es un contexto excelente para iniciar en primaria el modelo escolar de fuerzas que, por su carácter abstracto, suele reservarse para la educación secundaria.

Con la secuencia descrita, ayudamos a explicar y a predecir si un objeto se hunde o flota comparando el peso del objeto con el peso del agua que desaloja. De esta manera, podemos evitar las dificultades ocasionadas por el control de variables (masa, volumen) y por otras no determinantes para la flotación, como podrían ser la composición, la forma, etc. •

Nota

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Hemos hablado de:

- Didáctica de la física.
- Trabajos de investigación.

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