Narrative, visual, and didactic choices in the Supertroupers Project: designing a digital comic on energy

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Abstract

This paper reports on the design of a digital comic episode for teaching the concept of energy in secondary education. Developed through a collaboration between physics education researchers, a scriptwriter, and an illustrator, the episode introduces energy-related key ideas—such as physical state, transfer, conservation, and sources—through a fictional narrative centered on the construction of an hypothetical energy-generating device. The design was guided by a combined framework of Design-Based Research (DBR) and the Model of Educational

Reconstruction (MER), allowing for alignment between scientific content, student conceptions, and didactic structuring. Classroom testing of a prototype in France and Spain informed several revisions, including clearer sequencing of environmental issues and enhanced narrative coherence. The final resource remains to be tested. It is part of a multilingual series and is accompanied by teacher support materials. This case illustrates the affordances and boundaries of DBR and MER for designing multimodal educational artefacts in international contexts.

Keywords

Digital comics, energy, design-based research, model of educational reconstruction

Résumé

Cet article rend compte de la conception d'un épisode de bande dessinée numérique destiné à l'enseignement du concept d'énergie pour l'enseignement secondaire. Élaboré dans le cadre d'une collaboration entre des chercheurs en didactique de la physique, une scénariste et une illustratrice, cet épisode introduit plusieurs idées clés relatives à l'énergie (état physique, transfert, conservation, sources) à travers un récit fictionnel centré sur la construction d'un dispositif hypothétique de production d'énergie. La conception de cet épisode s'appuie sur un cadre articulant la Design-Based Research et le Model of Educational Reconstruction choisis pour soutenir une structuration didactique garantissant une mise en cohérence des contenus scientifiques en jeu avec les conceptions des élèves. L'expérimentation en classe de l'épisode dans sa version prototype en France et en Espagne a conduit à plusieurs révisions, notamment une clarification de la progression des questions environnementales et un renforcement de la cohérence narrative. L'épisode dans sa version finalisée reste à tester. Il s'inscrit dans une série de sept épisodes multilingues et s'accompagne de ressources destinées aux enseignants. Cette étude de cas met en évidence les apports et les limites de la Design-Based Research et du Model of Educational Reconstruction pour la conception d'artefacts éducatifs multimodaux dans des contextes internationaux.

Mots-clés

Bande dessinée numérique, énergie, Design-Based Research, Model of Educational Reconstruction

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Introduction

The concept of energy holds a central position in science curricula across many countries, yet numerous studies have shown that it remains difficult to teach and to learn (Goldring & Osborne, 1994; Liu & McKeough, 2005). Energy is not directly observable, can take on various disciplinary meanings, and is often confused with other quantities such as force, motion, electricity, or power. Students frequently interpret energy as a substance that flows, gets used up, or disappears—ideas that contrast with scientific models emphasizing conservation, transfer, and transformation.

Such conceptual difficulties are well documented and have been approached from different perspectives, including cognitive development (Wancham & Tangdhanakanond, 2023; Zhou & Traynor, 2022), linguistic ambiguity (Bächtold, 2018), and the epistemological structure of the energy concept itself (Coelho, 2014; Constantinou & Papadouris, 2012). Addressing these difficulties involves considering how learners make sense of invisible or abstract entities, and how representations can help or hinder conceptual understanding. Research in science education has explored the roles of analogies, models, and visual representations in helping students develop more productive ideas about energy (Liu & McKeough, 2005).

Comics have gained increasing recognition in science education and communication due to their capacity to combine narrative and visual elements, making complex phenomena more accessible and engaging (Farinella, 2018; Jee & Anggoro, 2012; Lin et al., 2015; Tatalovic, 2009). They can personify abstract concepts, present socioscientific issues within relatable contexts, and foster scientific reasoning through storytelling (Negrete & Lartigue, 2004). Research has shown that comics not only support comprehension but also promote the development of scientific skills, such as observation and inference (Lin et al., 2015).

Comics have also been successfully used to teach environmental topics, such as waste management, particularly at the primary and secondary education levels, with positive outcomes in content learning (Enteria & Casumpang, 2019). In addition to cognitive benefits, comics play a significant role in increasing motivation. Spiegel et al. (2013) found that comics effectively engaged adolescents with limited prior interest in science. The use of digital formats has expanded these possibilities further, enhancing motivation and attention in students, particularly in environmental education contexts (Damopolii et al., 2021).

While printed science comics have been the focus of several empirical studies (Bordenave & de Hosson, 2022), research on digital comics—that is, comics designed specifically for digital environments—remains scarce. Digital comics may include features such as interactive panels, animated transitions, and nonlinear navigation, which can modify the reader's engagement and interpretation (Fitria et al., 2023; Suprapto et al., 2024). These multimodal possibilities raise new questions regarding the epistemic and didactic potential of digital comics in science education.

This paper reports on the collaborative design of a digital comic on energy which is part of a webcomic series built around a shared narrative principle[1]. Each episode is narrated by four teenage members of a drama club, the *Supertroupers*, who stage performances that resonate with a scientific theme and serve as a vehicle for addressing scientific issues. Whenever possible, historical elements related to the targeted concept are woven into the storyline. In the energy episode, the *Supertroupers* explore the notion of energy while preparing a play about the design of a superpowerful energy-generating device, inspired by Leonardo da Vinci's inventions. Through exchanges with the stage technician, they confront real-world questions concerning energy transformations, conservation, and dissipation. Their dialogue and everyday experiences prompt them to consider whether energy can be "used up" and how to differentiate between useful and non-useful forms. By engaging with historical experiments and conceptual discussions, they gradually refine their understanding of energy and ultimately present to the audience an original performance that combines scientific insights with theatrical machinery. The entire design process is theoretically grounded in a combined framework drawing on Design-Based Research (DBR) and the Model of Educational Reconstruction (MER).

In the first part of this paper, we present the theoretical framework combining DBR and the MER. The second part introduces the research problem and the empirical basis of the design process. The third part describes the development of the prototype episode, its classroom implementation, and the revisions that led to the final version. Finally, the discussion highlights the main design constraints and levers, before concluding with implications for science education and teacher training.

Theoretical framework

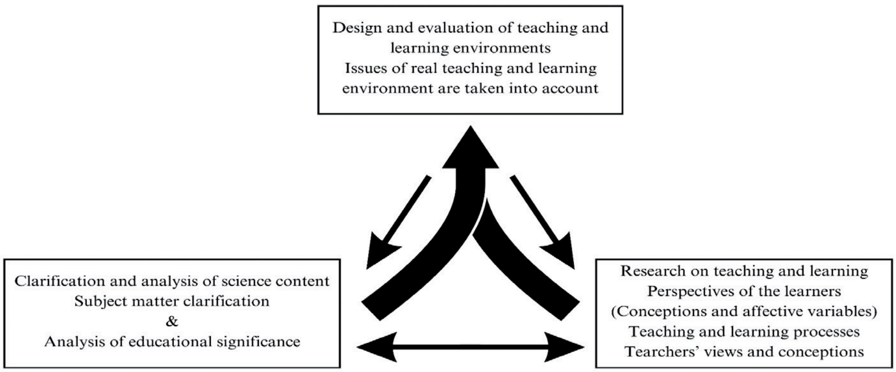
DBR supports the iterative development of educational innovations through cycles of design, implementation, and analysis in real-world contexts and it has been developed to bridge the gap between educational research and practice (Anderson & Shattuck, 2012; Barab & Squire, 2004; Collins, 1992). DBR is particularly suited to research contexts where educational innovations are developed and tested in real-world settings, in

1 ECOSCOMICS project - European Co-construction of a Science Webcomics Series - Projet Erasmus+ KA220-SCH n°2021-1-FR01-KA220-SCH-000030110.

close collaboration with practitioners. It enables the refinement of both instructional design and underlying assumptions by confronting *a priori* perspectives with empirical observations. DBR is characterized by its contextual nature, its iterative structure, its concern for theoretical development on specific contextual learning, and its aim to produce usable educational artefacts (Design-Based Research Collective, 2003). In this approach, the term artefact refers to any designed educational tool or intervention—such as a curriculum sequence, a simulation, or a digital comic—that is intended to support learning and is iteratively refined based on empirical observations.

To support the elaboration of the artefact, we draw on the MER (Duit et al., 2005). MER provides a framework to support the transition from scientific knowledge to teachable content, through three interconnected components (Figure I):

FIGURE 1



The three components of the Model of Educational Reconstruction [Adapted from Duit, Gropengießer, & Kattmann, (2011)]

Clarification and analysis of science content

This component involves a thorough examination of the scientific knowledge to be taught, including its conceptual structure, its epistemological status, and its historical development. It aims to identify the core ideas and underlying principles that should be preserved when scientific content is adapted for educational purposes. The clarification process may also highlight areas of complexity or controversy within the scientific domain, which can inform decisions about how content should be framed or transposed for learners.

Empirical investigation of students' perspectives

The second component focuses on identifying learners' prior knowledge, everyday language, and common misconceptions related to the scientific topic in question. These empirical insights help to uncover the cognitive and linguistic resources students bring to the classroom, as well as the potential obstacles they may face in understanding the targeted concepts. This dimension of the model emphasizes the importance of adapting teaching to the learner's perspective.

Construction of a content structure for teaching

The third component refers to the design of learning environments based on a coordinated consideration of three dimensions: the structure of scientific knowledge, learners' perspectives, and the characteristics of the medium through which knowledge is to be conveyed. This phase involves the selection, organization, and representation of content, as well as the development of instructional approaches that seek to foster conceptual intelligibility. The process also entails reflecting on how the medium itself—whether textual, visual, digital, or otherwise—shapes the possibilities for meaning-making and constrains the ways in which scientific ideas can be expressed, sequenced, and experienced by learners. A content structure for teaching is therefore not merely a matter of translation, but a reflective transformation that integrates epistemological, cognitive, and multimodal considerations.

The design also addresses teachers' concerns by providing supplementary resources and materials intended to facilitate the classroom use of the episode. These resources were conceived in parallel with the creation of the episode itself, emerging progressively through the collective design process but they are not examined in this paper.

Research aims

This study investigates the process of designing a digital comic aimed at supporting the learning of energy in lower and upper secondary science education. Specifically, it seeks to draw on a combined framework that articulates the DBR approach with the MER in order to produce an educational artefact developed under multiple constraints, including the nature of the scientific content, the diversity of teaching cultures involved, and the specificities of the digital comic medium. In this perspective, the research focuses on identifying the conditions, challenges, and productive dynamics involved in the co-design process. More broadly, the goal is to document and analyse how such a theoretically grounded design can inform the development of comparable resources, thus contributing to the modelling of design practices in science education.

Methodology of the design process

Conceptual foundations and initial design

The design process was grounded in a collaboration between partners from diverse cultural and professional backgrounds. It brought together physics education researchers from several European academic institutions (in France, Portugal, and Spain), a professional illustrator, and a scriptwriter. This interdisciplinary team worked through a series of regular meetings that structured the co-design process in successive phases. These included: (I) the identification of key conceptual targets and common student misconceptions; (2) the elaboration of a coherent conceptual progression; (3) the transformation of this progression into a fictional narrative and visual script; leading to the prototype of the digital comic (storyboard, combining didactic intentions with multimodal storytelling; (4) the analysis of the students feedback for the prototype revision.

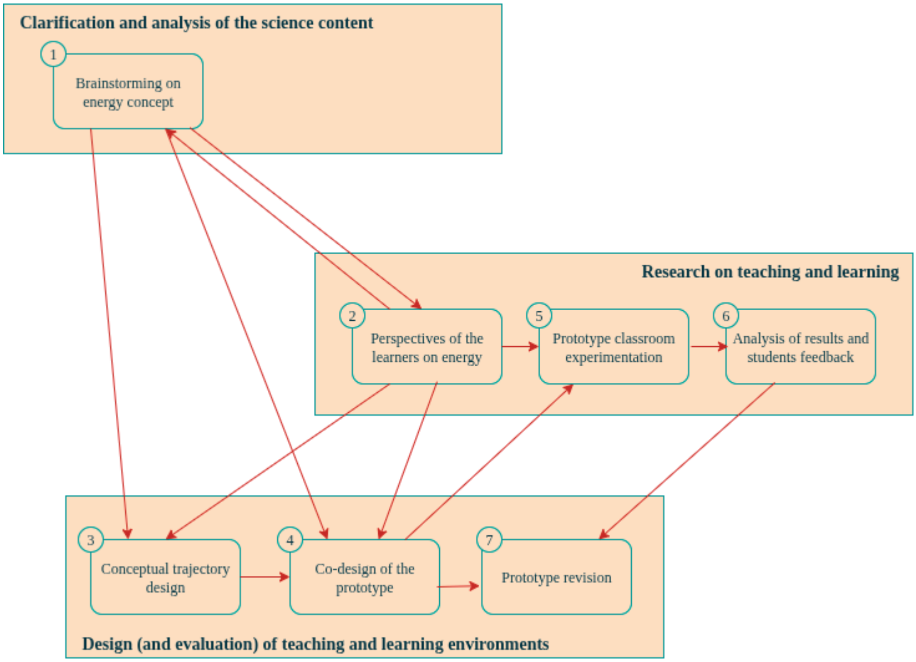
Testing and data collection

The prototype episode was tested in classroom settings in three European cities: Esparraguera and Vilanova (Spain), Toulouse (France), and Vincennes (France). Participating students were invited to complete a pre-test designed to explore their prior conceptions of energy and a questionnaire addressing their reading habits and familiarity with comic narratives. After engaging with the digital comic, students completed a post-test (conceptually equivalent to the pre-test) and a second questionnaire assessing their appreciation of the comic and its perceived clarity or difficulty. These empirical phases served two complementary purposes: (I) providing insights into students' ideas and interpretive processes, in line with the MER framework, and (2) informing iterative revisions to the comic's content, structure, and multimodal representations in accordance with the principles of DBR.

Refinement and final production

Based on the analysis of the classroom trials and collected data, the design team revised the episode to produce its final version. Changes included adjustments to the narrative flow, visual organisation of concepts, and clarity of scientific representations. The resulting episode reflects an articulation of research-based didactic intentions with the semiotic and narrative affordances of the digital comic medium. The entire process is summarised in Figure 2.

FIGURE 2



DBR modeling process of the final energy episode. The arrows indicate how each stage of the DBR process informed the others within an iterative perspective

FROM PROTOTYPE TO FINAL EPISODE: A DESIGN NARRATIVE

Scientific and narrative structuring of the prototype

The initial prototype was developed between July and December 2023. A first series of in-person workshops was held in July 2023, involving three 3-hour brainstorming sessions among the physics education researchers, followed by a 3-hour working session with the scriptwriter and another with the illustrator. These early discussions focused on defining the scientific trajectory, discussing the first narrative and visual ideas, (and visual tone) of the episode. Between September and November 2023, iterative exchanges took place remotely between the researchers, the scriptwriter, and the illustrator, leading to successive refinements of the storyboard. The prototype was finalised in December 2023 for classroom implementation.

The initial conceptual pathway was constructed with reference to documented learning difficulties concerning energy. Particular attention was paid to the abstract status of energy (which can not be easily constructed from sensory perception and/or direct observation), and the common confusions between conservation and disappearance, or between energy and other physical quantities like work and force. The selected progression aimed to support a gradual conceptual appropriation, starting from the idea of physical state (height, velocity, temperature, chemical composition, etc.), then introducing equivalence, change, transformation, and transfer, before addressing the distinction between useful and non-useful effects (energy "losses"), and finally the principle of conservation. This conceptual core was extended to include the notion of energy sources, with the explicit aim of linking physical considerations to environmental and societal issues which stood out from a curricular analysis performed in the three parting countries but especially present at France and Spain curriculum. For its part the curriculum in Portugal integrates a strong experimental approach to energy teaching fostering practical engagement. The distinction between carbon-based and non-carbon-based energy sources was introduced as a physical difference in terms of CO_2 emissions and their impact on climate change. The final part of the conceptual path therefore opens a space for interpreting energy choices in the light of sustainability and planetary boundaries. The conceptual framing was also supported by historical considerations, specifically, the inclusion of Joule's paddle-wheel experiment. It provides a bridge between mechanical and thermal processes, and illustrates how energy transformations can be quantified and understood without invoking a material substance. The integration of this reference aimed to support students' understanding of conservation beyond intuitive ideas of "disappearance".

Narratively, the episode is structured around a double task assigned to the four recurring protagonists of the series: they are asked to reflect on the possibility of designing a superpowerful energy-generating device and, at the same time, to compose a short theatrical scene in verse. The juxtaposition of a technical challenge and a poetic performance is designed to support the fictional dimension of the narrative (writing a play in the style of Renaissance machine theatre plays), and introduce a metadiscursive layer to the storyline. The *Supertoupers'* attempt to construct an energy-generating device first leads them to imagine a machine capable of transforming one form of energy into another, and ultimately to a perpetual motion machine. The idea of such a device—one that could operate indefinitely without external input—provides the narrative thread through which the conceptual difficulties surrounding energy transformations and losses are progressively explored.

The conceptual trajectory explored in the prototype episode was not intended as a continuous exposition but rather as a sequence of key learning moments each one comprising a chapter. They were specifically developed and tested during the prototype phase and are detailed below.

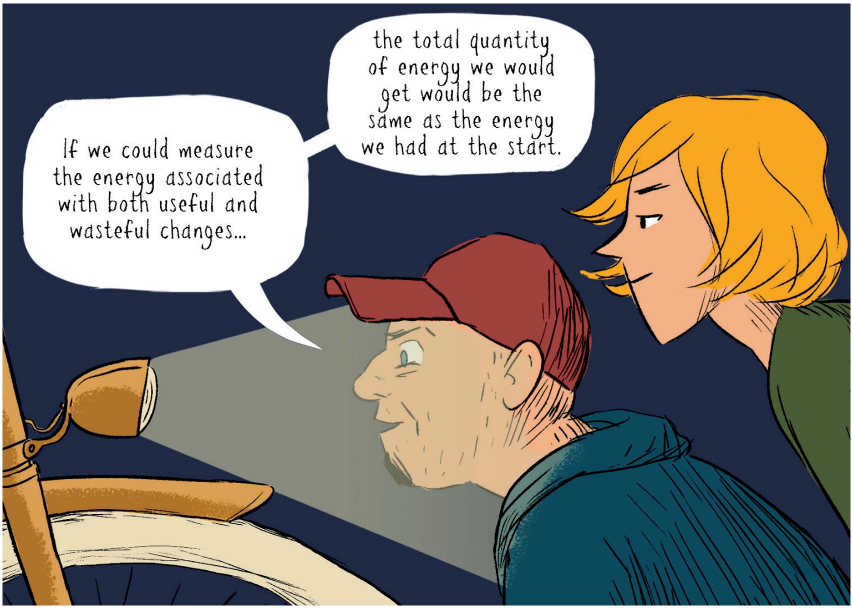
The first concerns the equivalence of energy in situations involving a system with different initial conditions. This was illustrated through a metaphorical scene in which candies of different masses fall into an ice cream from varying heights (Figure 3). The objective was twofold. From one side to support the idea that distinct initial conditions—such as a mass m dropped from a height 2h, or a mass 2m from height h—can produce equivalent effects and thus be associated with the same initial amount of energy. This allowed for the introduction of energy as a quantifiable property related to the state of a system. From the other side, this situation allows its enactment in the classroom.

FIGURE 3

Screenshot of the scene with candies falling into ice cream, from the Energy episode

The second design choice involved a bicycle-based sequence that models a chain of energy transformations. By tracing the energy transfer from the cyclist's effort through mechanical parts (pedals, gears, wheel), to a dynamo and ultimately a lamp as well as to the movement of the bicycle, the episode addressed several conceptual aims: to emphasise the non-substantial nature of energy, to distinguish between useful (light and movement) and non-useful (heat) effects, and to illustrate conservation across the system. The example also aimed to confront the common misconception that energy "disappears" as it moves through successive transformations, by focusing on the fact that the sum of useful and non-useful outputs equals the energy provided by the cyclist (Figure 4).

Figure 4



Screenshot of the scene where the distinction between useful and non-useful changes is first introduced to explain energy conservation along a transfer chain (here: a bicycle lamp)

The third choice was the introduction of Sankey diagrams as a visual representation of energy flows. These diagrams made it possible to present energy transfers in a quantitative manner. Besides, previous research has shown that Sankey diagrams can be appropriated by Grade 8 students and used productively to reason about energy in new contexts, supporting their potential as didactic tools (Vos & Frejd, 2022). In the prototype, *the Supertourpers* compare a compact fluorescent lamp and an incandescent bulb, based on their respective Sankey diagrams. The comparison highlights that for an equal amount of energy associated to light radiation (the useful effect), the fluorescent lamp required less energy input due to reduced energy associated to heat (the unuseful effect). In addition to their clarity and proportional accuracy, Sankey diagrams encourage both forward (from input to output) and backward (from observed effects to inferred sources) interpretations, which may foster systemic reasoning through a network of interrelated processes. This capacity is recognized as a central competency in science education: systems thinking supports the understanding of complex phenomena by enabling learners to model and reason about interactions, boundaries, and feedback loops (Bielik et al., 2023).

Classroom implementation and empirical feedback

The prototype was tested with Spanish students aged 14-15 (N=96), including 30 in Grade 9 and 66 in Grade 11, and with French students of comparable age (N=81). Rather than being conceived as a finished teaching tool, this prototype served as an exploratory artefact within an iterative design process. Its implementation aimed to generate insights into both students' conceptual understandings and their reception of the narrative, visual, and interactive dimensions of the digital comic format.

The evaluation of the prototype episode relied on a worksheet structured around six questions (Appendix 1). These questions addressed two complementary dimensions: key conceptual targets (equivalence, conservation, the distinction between useful and non-useful energy, and renewable sources), and the narrative thread of the episode (the *Supertroupers'* challenges of designing an energy-generating device, staging a theatrical performance, and optimizing energy consumption). Students worked in groups of four around a computer, using the episode as a resource to complete the worksheet. In addition, they were invited to provide open written feedback on their impressions of the episode.

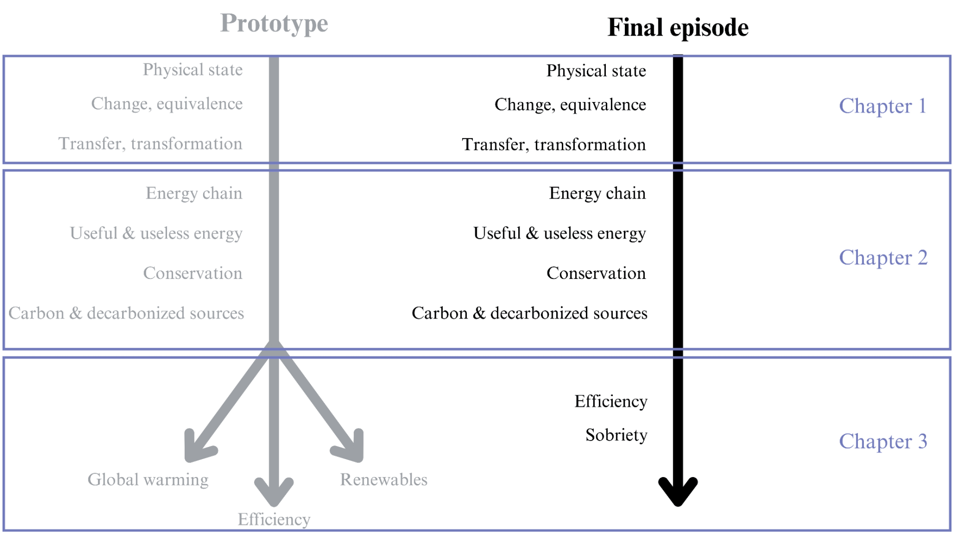
Overall, the responses indicated a good level of success regarding the targeted scientific concepts. Most groups were able to identify the principle of equivalence, describe energy conservation in simple terms, and differentiate between useful and non-useful energy within the examples presented. However, the questions addressing environmental issues proved more challenging: students experienced difficulties in making the principles of conservation and equivalence operational when applied to environmental issues. This difficulty was echoed in the open feedback. Some students reported that they found the distribution of information within the episode confusing, as illustrated by one comment: "*I found that the information was spread too unevenly*". Taken together, these elements indicate that the environmental dimension of the prototype was too dispersed across the storyline, which limited students' ability to connect scientific principles with their broader societal implications.

Students' responses provided useful guidance for the redesign. They revealed the need to strengthen the coherence of the environmental section, both conceptually and narratively, by presenting ideas in a more linear sequence and by clarifying the links between combustion and global warming. More broadly, these findings informed adjustments at several levels, including the conceptual trajectory, the organization of the narrative, the visual imagery, and the phrasing of dialogues, ensuring that the final version addressed both the scientific and environmental dimensions in a more explicit manner.

Revisions from prototype to final version

The most substantial changes were made in the third and final chapter of the episode, which introduces the environmental and societal dimensions of energy. In the prototype, this section combined multiple themes—combustion and CO_2 emissions, renewable energy sources, and the notions of efficiency and sufficiency—without a clear conceptual or narrative sequence. The design team restructured this section to establish a more linear conceptual flow. The revised version begins by distinguishing between carbon-based and non-carbon-based energy sources, establishing the connection between combustion and climate change through greenhouse gas emissions. This is followed by an exploration of the notions of energy efficiency and sufficiency. The overall content remained similar, but the transitions between ideas were made more gradual, reducing cognitive load and helping students to situate each element within a coherent trajectory. Figure 5 illustrates the conceptual and narrative trajectories underlying both the initial prototype and the final version of the episode.

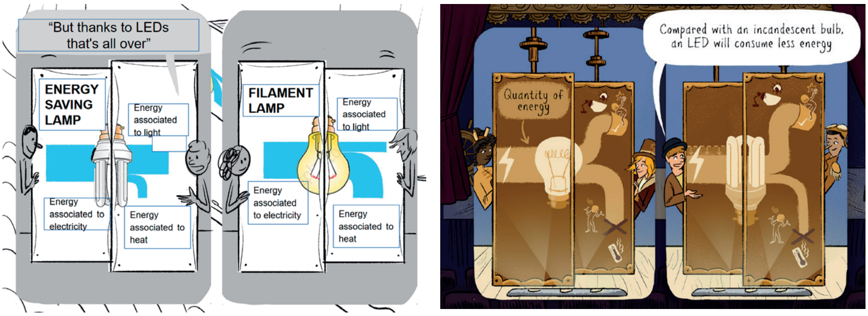
FIGURE 5



Conceptual pathway of the episode: prototype vs final version

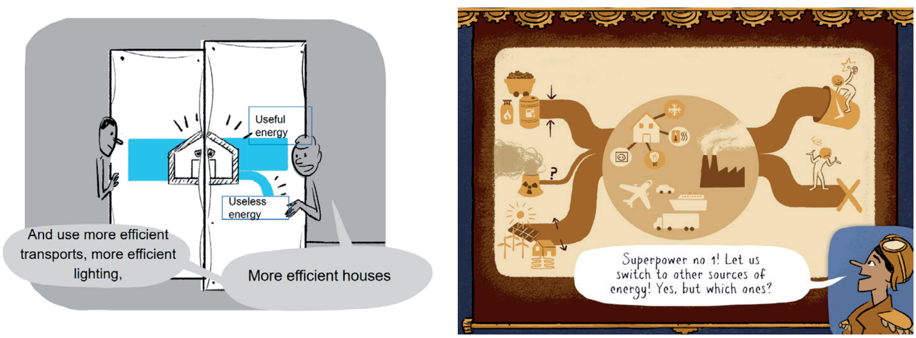
Beyond these adjustments, the student feedback also triggered renewed discussions within the design team, both among the researchers and between researchers and authors, since several initial choices had to be reconsidered and renegotiated. One example concerns the Sankey diagram comparing the efficiency of two lamps (Figure 6). A second major revision concerned the integration of the notion of sufficiency. This concept appeared useful for consolidating several elements that had previously appeared dispersed, while also providing an entry point to raise students' awareness of the broader societal challenges associated with adopting collective practices of sustainability at scale. The revised version therefore introduced a change of perspective, shifting from a focus on local energy systems to more general ones (Figure 7). This modification, however, prompted further debate within the design team regarding the representation of nuclear energy. While some members argued that it should be included within the category of non-carbon-based sources, others maintained that it should be presented separately, since its environmental risks, though distinct from greenhouse gas emissions, remain significant. The team ultimately agreed to depict nuclear energy as a distinct subcategory of non-carbon-based sources.

Figure 6



Adaptation of a Sankey diagram comparing two lamps. Between the prototype version (left) and the final version (right), the choice was made to keep the amount of useful energy constant in order to highlight that the low-consumption lamp (LED) produces less non-useful energy for the same brightness and therefore requires a smaller energy input. In addition, the more efficient lamp was placed after the other in the reading order, in line with common conventions

Figure 7



From dispersed themes to a systemic framing: integration of sobriety and separate treatment of nuclear sources within the non-carbon-based category

At last, whereas the prototype was based on a sequence of static digital images that advanced on click, the final version was designed to incorporate short animations at selected points where dynamic visualisation could enhance meaning. These included the falling motion of candies in the energy equivalence scene, the paddle-wheel turning in Joule's historical experiment, the illumination of the bicycle-powered lamp, and the variation of input and output flows in the Sankey diagrams. In each case, the animation served to reinforce key ideas by making visible temporal progression, causal links, or proportional change—affordances that would have been more difficult to convey in a static format of classic printed comic book.

Discussion: design constraints and levers

The design process was shaped by multiple constraints—conceptual, narrative, semiotic, and institutional—and was continuously informed by the iterative interplay between design intentions and empirical observations. Several specific choices illustrate how the affordances of the medium and the contributions of the artistic collaborators influenced the final episode. These choices merit further discussion, as they depart in significant ways from conventional didactic treatments.

One of the most distinctive choices was to introduce energy sources only at the end of the episode, rather than as an entry point to the topic. In many school curricula and textbooks, energy is initially introduced in terms of its sources—solar, wind, fossil fuels—often with a quick link to electricity production or environmental impact. By contrast, the conceptual sequence adopted here postpones this dimension until after the notions of state, transfer, usefulness, and conservation have been established. The rationale was to construct a more coherent chain of reasoning: one in which the reader first acquires tools for describing changes, comparing situations, and quantifying transfers, before being introduced to broader societal and environmental questions. This inversion of the usual sequence was intended to strengthen conceptual foundations and allow the final section to be framed not as a list of types of energy, but as an invitation to reason about systems, transformations, and long-term sustainability.

A second decision concerned the vocabulary used to characterise energy transformations. The term 'non-useful energy' was deliberately chosen instead of 'losses' or 'waste', in order to avoid the common misconception that energy disappears or is destroyed. Although unconventional, this terminological choice was found to be more accessible to students and consistent with the educational aim of distinguishing between physical transformation and functional value. One reason for that was the international and interdisciplinary nature of the design team. Researchers from France, Portugal, and Spain, all with backgrounds in physics education research, brought with them distinct curricular references, classroom experiences, and didactic traditions.

Because the episode—like the rest of the serie—was intended for publication in several languages with identical conceptual, narrative, and visual content, the team could not rely on any single national framing. Instead, they were compelled to build a shared conceptual structure and to choose examples and narrative devices that were intelligible beyond local school habits. This constraint, while initially challenging, proved to be generative. While the researchers in the team were accustomed to the institutional routines specific to science education in their respective countries, and their proposals reflected these traditions, the collaborative process enabled them to transcend such norms and to construct a consensual didactic approach. This distancing from national pedagogical norms may help explain the originality of certain choices—such as the sequencing of concepts, the selection of metaphors, and the narrative framing—which might not have emerged within a single-country design context.

On the narrative side, once one of the characters proposes the perpetual motion machine as a possible theatrical device, the script uses this idea to carry the reader through the subsequent conceptual progression. This challenge, although physically impossible, is frequently portrayed in online videos that simulate working devices through concealed tricks. By engaging with the idea from within the story, the episode not only exposes the fallacy but also uses it as a narrative lever to unpack key scientific ideas—such as the inevitability of unuseful energy, the limits of efficiency, and the impossibility of producing work indefinitely without input.

Several elements of the conceptual and narrative structure emerged directly from the collaboration with the artistic contributors. The sequence intended to illustrate the equivalence of initial energy in distinct physical states was first outlined by the science education research team within the conceptual trajectory and discussed during in-person brainstorming sessions.

The scriptwriter's proposal of depicting two sweets falling into an ice cream was subsequently incorporated into the conceptual narrative as a relatable real-life example. The same ice cream then becomes the food consumed by the cyclist, who generates energy to power a lamp—thus introducing the notion of transfer and chaining. From there, the storyline unfolds to connect this everyday scenario to a larger energy system, tracing back to the cow that produced the milk, the grass that fed the cow, and the sunlight that sustained the grass. This narrative arc eventually leads to the notion of energy sources, creating a meaningful and coherent transition from individual experiences to global concerns.

Finally, the figure of the stage machinist plays a pivotal role in the episode, guiding the protagonists through their tasks and conceptual explorations. By asking questions, proposing experiments, and highlighting inconsistencies, the stage machinist serves as a narrative agent of didactic scaffolding (Wood et al., 1976). Indeed, the interventions structure the flow of ideas without assuming the authority of a teacher or narrator, preserving the autonomy of the characters while enabling a form of guided inquiry. The stage machinist thus embodies a hybrid function—both fictional and pedagogical—that was only made possible through close collaboration between researchers and creative partners.

Conclusion

This paper reports on the collaborative design, implementation, and revision of a digital comic episode aimed at supporting students' understanding of energy. The episode was developed within a multilingual, interdisciplinary research project involving science education researchers, a scriptwriter, and an illustrator.

The overall process was framed by a combined theoretical approach articulating DBR and the MER. DBR supported an iterative, collaborative and context-sensitive design logic, in which empirical feedback was used to inform revisions at multiple levels—conceptual, narrative, and visual. MER provided a structured framework for integrating the clarification of content, the analysis of students' prior ideas, and the didactic transformation of knowledge. This articulation proved productive: it enabled the team to select relevant conceptual landmarks, identify obstacles in interpretation, and construct representations aligned with learners' cognitive and epistemological needs. However, the framework also has its limitations. Neither DBR nor MER addresses in detail the challenges specific to narrative construction, multimodal readability, or the coordination of semiotic registers across text, image, and animation. These dimensions had to be negotiated in collaboration with the artistic contributors and refined through empirical testing.

The design was further shaped by an important institutional constraint: the final product had to be identical across seven language versions. This requirement compelled the design team to distance itself from national curricular traditions and collectively construct a storyline that was not necessarily embedded in one pedagogical culture. In doing so, the team arrived at a structure quite different from school-based routines.

The final version of the episode has not yet been tested in classroom settings. A second round of implementation is currently being planned in the project's partner countries. In parallel, the team is designing a teacher education programme to support the pedagogical use of the episode. The resource is explicitly intended for teachers, and its classroom use will depend on how it is integrated into their professional routines and curricula. Additional materials—such as the pre/post tests, historical notes, and pedagogical guidelines—are available on the project's website (https://www.supertroupers.eu/en). Further research is needed to understand how these complementary tools are interpreted, selected, or adapted by teachers, and how they shape the instructional use of the episode.

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Appendix: worksheet answered by the students during the classroom testing of the prototype

Q1
In this episode, the Supertroupers must complete two tasks assigned to them by their theater teacher. What are these tasks? Do they succeed? For what reason(s)?

Q2
In the experiment conducted by the stage manager, why do the two candies fall to the same depth in the icecream?

Q3
What does the principle of conservation of energy mean? Is it rigorous to speak of "losses" and "dissipation" of energy?

Q4
Why is it impossible to generate a strictly perpetual motion?

Q5
Is a renewable energy source inexhaustible? Explain the difference.

Q6
What solutions do the Supertroupers propose to optimize energy production and consumption while reducing losses?
