Futures education: an oscillation between knowledge and opinions

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ABSTRACT

This contribution is based on the joint mobilization of the scenario-building method, socially acute questions (SAQ) didactics and education about future, risks and uncertainties, in designing a teaching device on gene drive as a controversial technoscience. In order to explore its impact, this device has been tested with students of Life and Earth Sciences in Tunisia. The comparative analysis of the answers to two pre and post experiment questionnaires shows a positive effect on the acquisition of scientific knowledge and its influence on the students' opinions. The results also show that students' interest in gene drive is not adversely affected by exposure to controversies, risks and uncertainties related to the application of gene drive. In order to deepen the results found, we intend to study the scenarios built and the opinions expressed during the device.

KEYWORDS

Gene drive, teaching device, scenario-building method, pre-service teacher, Life and Earth Science, opinion, technoscience, Socially Acute Question (SAQ)

RÉSUMÉ

Cette contribution se fonde sur la mobilisation conjointe de la méthode de construction des scénarios du futur, la didactique des questions socialement vives (QSV) et la perspective des éducations au futur, aux risques et aux incertitudes dans la conception d'un dispositif d'enseignement sur le forçage génétique en tant que technoscience controversée. En vue d'explorer son impact, ce dispositif a été expérimenté avec des étudiantes de Sciences de la Vie et de la Terre (SVT), en Tunisie. L'analyse comparée des réponses à deux questionnaires ante et post expérimentation montre un effet positif du dispositif sur l'acquisition des connaissances scientifiques et son influence sur les opinions des étudiantes. Les résultats montrent aussi que l'intérêt que portent ces étudiantes envers le forçage génétique n'est pas impacté défavorablement par l'exposition aux controverses, risques et incertitudes liés à l'application du forçage génétique. Afin d'approfondir les résultats trouvés, nous envisageons d'étudier les scénarios prospectifs construits et les opinions exprimées lors du dispositif.

MOTS CLÉS
Forçage génétique, dispositif d'enseignement, méthode des scénarios, futur enseignant, Science de la Vie et de la Terre, opinion, technoscience, Question Socialement Vive (QSV)

INTRODUCTION

The didactics of socially acute questions (SAQ) focuses on the conditions for studying objects that are complex and controversial in the social and scientific sphere. Risk and uncertainty are often identified as characteristics of these objects on the one hand and are intrinsically linked to the future on the other. Therefore, how can SAQ didactics jointly contribute to education about the future, risk and uncertainty?

Our research aims to investigate this question on two levels. From an operational point of view, we designed and experimented with students of Life and Earth Sciences in Tunisia a didactic sequence on the gene drive, highlighting the risks and uncertainties of this nascent biotechnology. For this, we have been inspired by the scenario-building method in futures studies to aim at education about the future, risk and uncertainty. From an analytical point of view, we explored the impact of this deployment on the acquisition of scientific knowledge and the construction of informed opinions, and we examined the potential evolution of students' interest in this controversial technoscience. In the following, we develop the theoretical foundations on which our analytical reflections and methodological orientations are based.

REVIEW OF LITERATURE

Gene drive is a form of biotechnology that enables the production of organisms through genome manipulation. It is based on the application of the CRISPR/Cas9 system, which is used to achieve precise genetic cuttings and enables rapid and targeted propagation of genetic modifications within natural populations (Mansouri & Collombat, 2020). Its potential applications are numerous, affecting not only public health, but also agriculture and conservation biology (Courtier-Orgogozo, 2019), which is why the 2020 Nobel Prize in Chemistry was awarded to two pioneers of this approach. Given its precision and efficiency, gene drive represents one of the major scientific advances of the twenty-first century and generates, at the same time, several biological and ethical questions. Gene drive can be described as technoscience if one looks at the four characteristics given by Bensaude-Vincent et al. (2011):

- Technoscience produces objects that are affectively, axiologically and socially invested by social actors, and these objects are controversial. Chneiweiss (2017) shows that the controversy over gene drive raises several questions such as the degree of stability of the genetic modifications produced and the reliability of the technique and associated risks such as the risk of modifying a non-target gene or the risk of a single strand of DNA being severed. Wedell et al. (2019) highlight other ethical risks associated with gene drive, such as the risk of spillover of modified genes into non-target populations and species.
- The objects produced by technoscience are performative: they are defined more by their technical performance and what they are capable of doing, rather than by their nature. The gene drive is thus generally presented by the promises it represents for the fields of health and agriculture.

- The objects produced by technoscience are familiar: they are represented as effective manipulation that are easily incorporated into everyday objects. Legros et al. (2021) thus explain that all food production could benefit from the effects of gene drive, replacing the use of pesticides in agricultural systems.
- The objects produced by technoscience have an unlimited materiality: they allow to create physical, chemical or biological characteristics, which can be easily modified under certain conditions to suit specific uses. In the case of gene drive, all living organisms can be genetically manipulated.

Saoudi and Bouamoud (2024) were interested in the study of gene drive, as a socially acute question, with Life and Earth Sciences students, they show that teaching such technoscience involves confronting students with the risks and uncertainties of its development.

For Nedelec (2018), uncertainty is associated with both the conditions of knowledge generation and the different possibilities of its use in society. He thus distinguishes five forms of socio-epistemic uncertainties related to technoscience: epistemic uncertainty; uncertainty of effects; uncertainty of decisions; uncertainty of actors; uncertainty of uncertainty. Nedelec (2018) highlights the complexity of the concept of uncertainty and the links between risk and uncertainty: "it is the magnitude of uncertainty that shapes the contours of risk (the greater the degree of uncertainty, the more multiple and shifting the risk)" (p. 81). The concept of uncertainty is often used simultaneously with the concept of risk. However, they have different meanings and definitions. Risk is not tangible, but rather virtual and potential. This inherent ambiguity makes it a difficult concept to delineate (Kermisch, 2012). In the literature, different types of risk can be distinguished: technical risks, which may have impacts that are difficult to calculate (Laganier et al., 2023); environmental risks, which are perceived as difficult to control (Fleury-Bahi, 2010); Ethical risks, which reflect a situation that may lead to negative outcomes related to integrity and ethics; social risks, which concern potential changes in the social relationships of individuals, as well as the individual's connection to society (Lefeuvre-Halftermeyer et al., 2017); political risks, which are related to conflict situations that may negatively affect the political or governmental stability of a country (Daniels et al., 2018); health risks, which represent a direct danger to human health (Ameline & Levannier, 2021).

From the perspective of SAQ didactics, risk and uncertainty are entangled in social-scientific and socio-technical controversies. However, these two concepts are rarely recognized as knowledge that can form full-fledged teaching content (Schenk et al., 2021), while they are considered useful in informing opinions and decisions about SAQ (Covitt & Anderson, 2022). Uncovering uncertainties and identifying risks can thus lead learners to build a "reasoned opinion" (Lange et al., 2007) on SAQ, i.e. to develop the ability to convene multi-referential arguments, to highlight the contradictions arising from rationality, and overcome them by adopting a dialogical posture (Morin, 2018). Nedelec and Molinatti (2018) consider that teaching devices based on futures studies are particularly relevant to understand the uncertainties inherent in SAQ, because they allow 'to make the uncertainties of contemporary questions a completely manipulable subject for experimentation" (p. 79).

However, there is limited research on these devices. The use of the scenario-building method has led to some experiments in science education (Barelli, 2022; Buntting & Jones, 2015; Jones et al., 2012), as well as the writing of futures narratives (Hervé et al., 2021; Panissal & Plégat-Soutjis, 2018). The main results show above all the feasibility of implementing these teaching devices, the involvement of young people in epistemic tasks, the importance of mastering scientific knowledge for the arguments developed, and their relevance for investigating the social nature of science and technology (Barelli, 2022; Buntting & Jones, 2015), ethical thinking (Panissal & Plégat-Soutjis, 2018) and futures thinking (Hervé et al., 2021), and tensions and conflicts of interest between stakeholders regarding the strategies to be implemented (Barelli, 2022).

Since Godet states that "there is not one method of building scenarios but a multitude of ways to construct scenarios (more or less simplistic, more or less sophisticated)", it seems interesting to explore these varied and flexible methods further, and this is indeed one of the aims of the present work.

MATERIAL AND METHODS

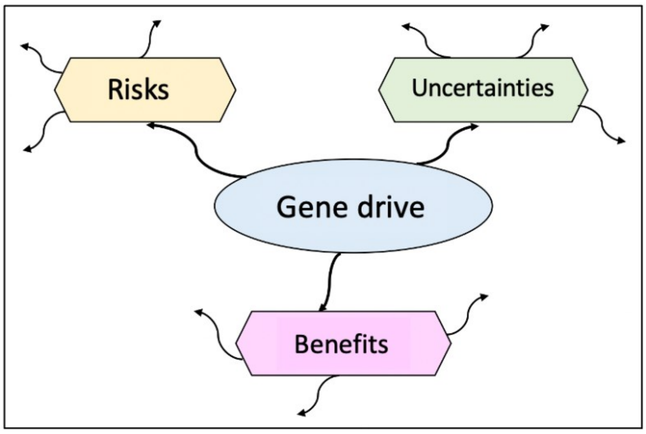
Our research methodology is based on a pre/post questionnaires (QPP pencil paper; multiple choice QMC) and on a didactic engineering that uses video sequences on gene drive as teaching materials, and aims at the building of future scenarios. A framework of activities has been designed for building future scenarios. These activities are inspired by the scenario-building method used in futures studies.

Our experiment is carried out in four stages (Stg1, Stg2, Stg3 and Stg4), during which we implement the didactic engineering with a group of 23 female students in the third year of fundamental bachelor's degree in Life and Earth Sciences of the Bizerte Faculty of Science (FSB) in Tunisia. These are female students who intend to teach Life and Earth Sciences. For this reason, we call them "future potential teachers" (FPT).

The experimental protocol is spread over five weeks and begins with the pre-test stage Stg1, during which the students initially respond, a questionnaire QPP containing questions to collect information on the participants' age and academic background. In a second stage, the students watch a series of introductory videos on gene drive, this stage ends with the completion of the QMC1 questionnaire containing multiple choice questions related to the following themes: technoscience, biotechnology and gene drive, the concepts of uncertainty and risk associated with gene drive and opinion questions.

Two weeks later, the integration of the first part of the system is based on the viewing of three series of video sequences for the realization of three activities. The video media were selected for their potential to present in a concrete and visual way testimonies and reports highlighting uncertainties, the risks and benefits associated with the application of gene drive, as well as the various stakeholders involved. The launch of the device is made with the viewing of four video sequences followed by the realization of Activity 1 which consists of completing, in groups, the framework of a conceptual map represented by Figure 1, highlighting the uncertainties, risks and benefits associated with gene drive.

FIGURE 1



Framework of the concept map to be completed as part of activity 1

Activity 2 follows with the objective of getting students to identify the actors involved in the implementation of gene drive and then to assess their degree of dependence and influence, based on the content of a third series of video sequences. The last activity of this first part of the device is Activity 3 which deals with the identification of the drivers of change whose variation influences the development of gene drive (Example of a driver of change: the purpose of gene drive). To help students complete this activity, they watch a fourth series of video clips.

One week after the first part, the next part of the process involves four consecutive activities. In Activity 4, groups of students ask questions about the drivers of change identified in Activity 3 of the previous step. In Activity 5, each group of students answers the questions raised during Activity 4, which allow them to make a set of hypotheses about the evolution of each driver of change identified during Activity 3 (Examples of evolution hypotheses corresponding to the driver of change relating to the purpose of gene drive: hypothesis 1: fight against disease; hypothesis 2: improve world food production; hypothesis 3: increase financial profits for multinational corporations; hypothesis 4: modify the human genome). For Activity 6, each group is asked to construct three scenarios for the evolution of gene drive by 2050, based on three different combinations of assumptions, from Activity 5. Three scenarios are thus constructed: a trend scenario, a pessimistic scenario and a desirable scenario. The final activity, in groups, is Activity 7, which consists of reflecting on possible strategic recommendations to achieve the desirable scenario. This second part of the project ends with the individual writing of a text in which students express their opinion regarding the uncertainties and risks associated with the application of gene drive.

The post-test Stg4 is the last stage, experiment takes place after two weeks, during which the students answer the QMC2 questionnaire, which is identical to the initial QMC1 questionnaire.

Data processing

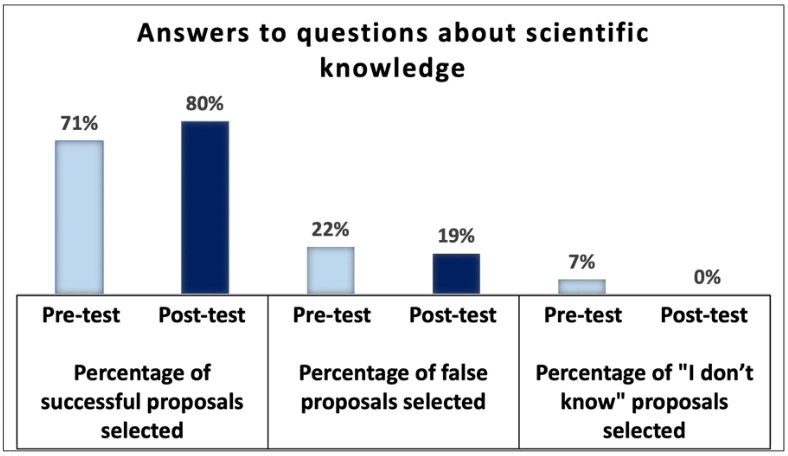
In this study, we analyze the responses to the two multiple-choice questionnaires QMC1 and QMC2. Once the answers have been tabulated, we analyze them for each student (question by question) and then compile the analyses for the entire class group. First, we focus particularly on the analysis of the answers to the six questions on scientific knowledge: Q1, Q2, Q3, Q4, Q6 and Q7, seeking to evaluate the evolution of the acquisition of scientific knowledge, by comparing the answers given at the time of the pre-test with those given at the time of the post-test. Then we focus on the analysis of four opinion questions: Q12, Q14, Q17 and Q19. On the one hand, we seek to focus on the possible change in opinion of these students by identifying their initial opinions at the time of the pre-test and comparing them with their opinions given at the time of the post-test. On the other hand, we are interested in the frequency of opinion change by determining for each student the number of times she changed her opinion.

We conclude by analyzing the answers given to question Q21, which reveals the students' interest in gene drive. The analysis of this question consists in focusing on the students belonging to the following fourth interest classes: Not at all interested, Moderately interested, Interested, Very interested.

RESULTS

Six questions deal with scientific knowledge: Q1 (What is technoscience?); Q2 (In which fields are technoscience applied?); Q3 (Which of the technologies listed below are considered to be applications of technoscience in the biological field?); Q4 (What is biotechnology?); Q6 (What is gene drive?); Q7 (Which of the following operations have become possible through the technology of gene drive?). Analysis of the answers given to these questions shows an increase in the percentage of correct proposals selected by the students at QMC2 level, from 71% for QMC1 to 80% for QMC2. At the same time, we note a slight decrease in the percentage of false answers selected, from 22% in QMC1 to 19% in QMC2. We also note the absence of "I don't know" responses in QMC2 while at in QMC1 level, 7% of the "I don't know" responses were selected. These different results are shown schematically in Figure 2.

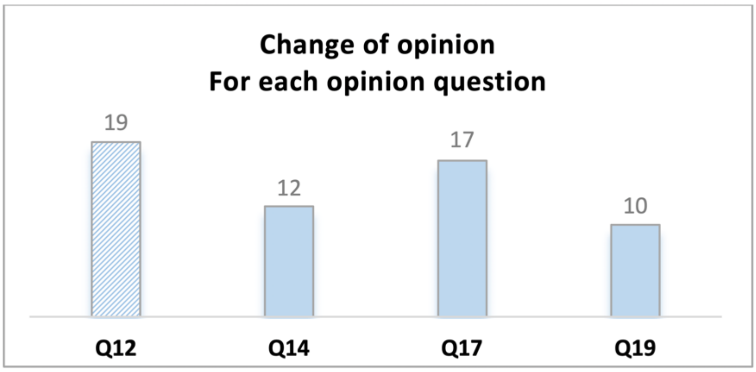
FIGURE 2



Representation of the percentage of selected answers to scientific knowledge questions during pre-test and post-test

The analysis of the answers given for the four opinion questions shows that out of the 23 participants, 19 students changed their opinion regarding Q12 (According to you, the uncertainties related to the application of gene drive would be directly related to....?), 17 students changed their opinion regarding Q17 (In your opinion, what is the measure(s) to be taken by states to manage the risk of deviation from gene drive applications?), 12 students changed their opinion regarding Q14 (Do you think that the uncertainties related to the application of gene drives could be brought under control, in the future?) and 10 students changed their opinion for Q19 (Do you think the benefits of gene forcing would justify accepting the uncertainty and risk, related to the application of this technique?). For these four questions, the rates of change of opinion are significant, ranging from 43% (for question Q19) to 83% (for question Q12). These results are schematically represented in FIGURE 3.

FIGURE 3

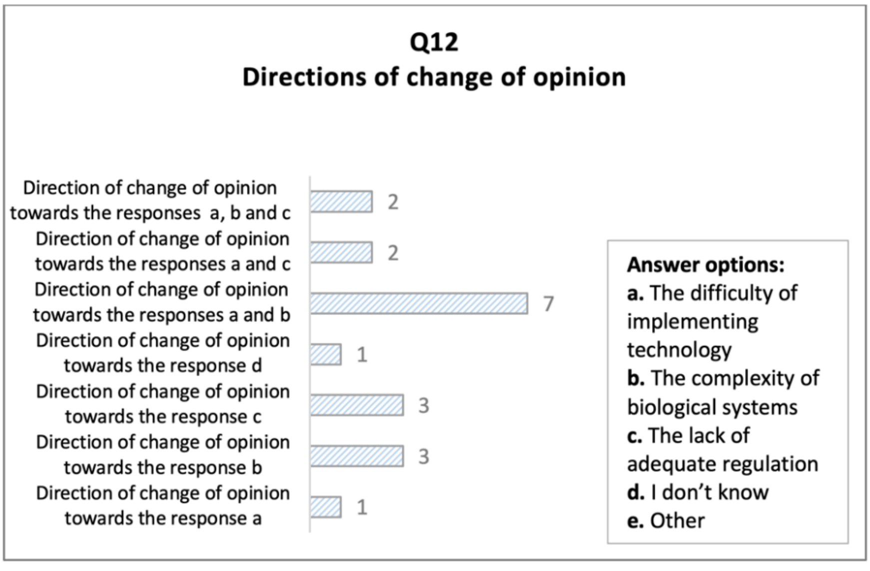


Representation of the number of students who have adopted a new opinion on each opinion question

Analysis show that question Q12 (According to you, the uncertainties related to the application of gene drive would be directly related to....?) is the opinion question that has experienced the most significant changes in responses. We are therefore interested in the direction of change of opinion observed for this question. It should be noted that for Q12, five distinct response options are offered to students (a. The difficulty of implementing technology; b. The complexity of biological systems; c. The lack of adequate regulation; d. I don't know and e. Other). A comparative analysis of the responses to Q12 at both times (pre-test and post-test) indicates that changes in opinion are mainly oriented towards options a (the difficulty of implementing technology) and b (the complexity of biological systems), present together in 9 responses and separately in 6 responses. Seven distinct trajectories of opinion change were identified among the nineteen students (FIGURE 4):

- Seven students oriented themselves towards the joint selection of the two responses a and b. For these students, gene drive uncertainties arise equally from technological implementation challenges and from the inherent complexity of biological systems.
- Three students retained only the answer b. For these students, uncertainties surrounding gene drive application stem exclusively from the complexity of biological systems.
- Three students modified their response to opt for the response c. For these students, gene drive uncertainties are linked to one factor alone: the lack of adequate regulation.
- Two students oriented themselves towards the joint selection of responses a and c. These students attribute gene drive uncertainties to both technological implementation challenges and inadequate regulatory oversight.
- Two students opted for a multiple response by selecting answers a, b, and c. For these students, uncertainties surrounding gene drive application stem from three interconnected factors: implementation challenges, biological system complexity, and inadequate regulation.
- A student turned to the answer a. This student attributes gene drive uncertainties solely to the technical challenges of implementation.
- Only one student selected the "I don't know" response option, indicating either an inability or unwillingness to express a position regarding the uncertainties associated with gene drive application.

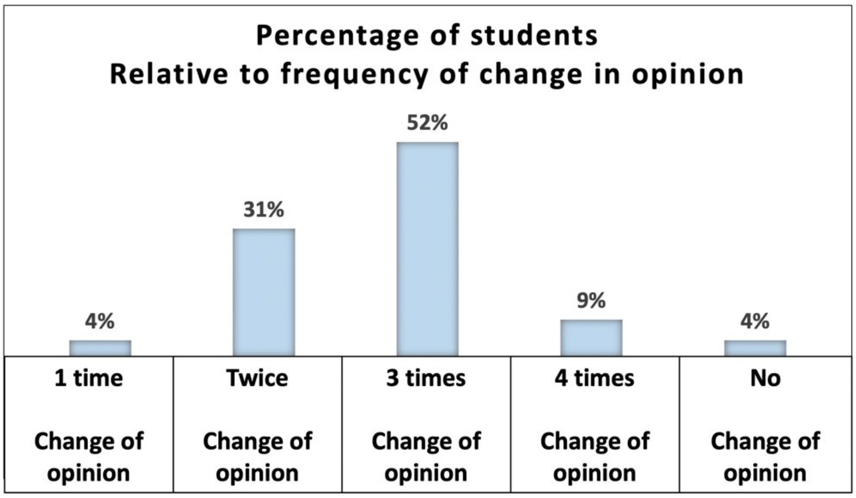
FIGURE 4



Representation of the directions of opinion changes for the Q12 and the number of students concerned by each direction

Analysis of the frequency of change of opinion shows that most students (52%) changed their opinion three times during the experiment. Followed by the group of students who changed their opinion twice with a percentage of 31%. Next, we find those who have changed their opinion four times: FPT10 and FPT24, representing 9% of our sample. The FPT19 student changed her mind once, representing 4%. Of all the students, we only found one student FPT4 who did not change her opinion on any of the four questions. In other words, with the exception of the FPT4, all the other students changed their opinion at least once during the experiment. These results are shown schematically in FIGURE 5.

FIGURE 5

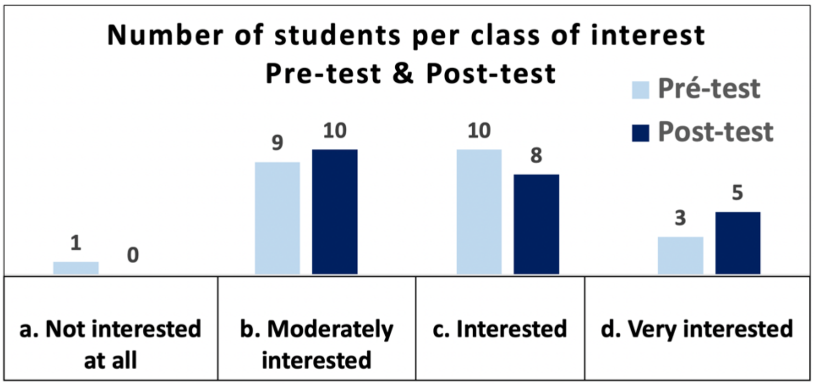


Representation of the percentage of students with the same frequency of change in opinion

Analysis of the responses to Q21 (Where do you place your interest in gene drive?) shows that the class “Interested” is the most represented at the time of the pre-test with 10 students. By the post-test, however, this class had become less representative, with 8 students. Conversely, the “Moderately interested” class is more represented in post-test than in pre-test. With 9 students in pre-test and 10 students in post-test. We note that the two classes “Interested” and “Moderately interested” are represented, on their own, by more than ¾ of the students, both in pre-test and post-test. The” Very interested” class is more represented in post-test than in pre-test with 3 students in pre-test and 5 students in post-test. For the “Not at all interested” class, there is only one student in the pre-test and none in the post-test. For the 8 students who have changed their class of interest and who represent 35% of all participants, variations were made in several directions: 4 students were directed to the” Moderately interested” class, 2 students went to the “very interested” class and 2 other students went to the “Interested” class. These results are shown schematically in Figure 6.

Analysis of the trends in choice of interest classes shows that 15 students chose the same interest class in the pre-test and post-test, and 8 students changed their response during the post-test, according to the following trends: 3 students switched from “Interested” class to “Moderately interested” class, one student switched from “Interested” class to “Very interested” class, one student switched from “Moderately interested” class to “Very interested” class, 2 students switched from “Moderately interested” to “Interested” and one student switched from “Not at all interested” class to “Moderately interested” class. We note that 5 out of 8 changes in interest class choice led to higher classes in terms of interest in gene drive.

FIGURE 6



Schematic representations related to the overall analysis of Q21

DISCUSSION

The increase in the number of correct proposals selected at the time of post-test, accompanied by a decrease in the number of incorrect responses selected, on the one hand, and the absence of "I don't know" type answers on the other hand, show an improvement in the acquisition of scientific knowledge. This supports the hypothesis of the positive impact of the didactic system implemented on the acquisition of scientific knowledge. The results found point in the same direction as those found by Saoudi and Bouamoud (2024), who, following the integration of the theme of gene drive taught as a SAQ with Life and Earth Sciences students, show that there is an improvement in the acquisition of scientific knowledge. The results also align with the conclusions of Simonneaux (2003), who, by working on the debate situations on animal transgenics, shows that debate on SAQ can not only be a source of motivation for learners but also can promote the appropriation of scientific knowledge. The results found are similar to those of Jones et al. (2012), who, by using the scenario-building method applied to three categories of students aged between 8 and 16, show that the pedagogical sequence focused on building future scenarios is an introduction to subsequent scientific learning on the subject treated, and that the activities in this sequence also allowed students to critically reflect on their technical knowledge, while introducing the study of later scientific knowledge.

The high rates of change in opinion for all students points to the impact of the system deployed on opinions. On the one hand, this could highlight a difficulty in building a stable and consolidated opinion taking into account the concepts of uncertainty and risk in relation to a scientific theme. According to Lange et al. (2007), reasoned opinion is a thought in construction and movement that emphasizes questioning and research. Thus, if we consider the change of opinion as indicator that testifies to the functioning of a process of construction of a reasoned opinion, in this case we can say that our system is a tool which supports the construction of a reasoned opinion favorably since it has generated high rates of opinion change. Furthermore, since SAQ involve ambiguous situations that can lead to a multitude of possible resolutions, the treatment of these issues calls for a dual approach. The aim is to clarify events or phenomena, and at the same time to encourage decision-making by highlighting the scale and scope of the issues as well as the impact of the various possible decisions. Decision-making is based on rational reflection, being aware that the scientific source of information is not sufficient to choose or decide, since choices necessarily refer to values (Chauvigné & Fabre, 2021). Based on this analysis, we can assume that during our experiment, these students, at the time of the pre-test and before studying the problematic aspects, answer the opinion questions relying only on their scientific knowledge, as they are used to. But at the post-test time, after studying the social, ethical and political dimensions of risk and uncertainty, these same students decide to opt for new opinions. Being exposed for the first time to such controversy in the context of scientific teaching has destabilized them and led them to change their opinion to implicitly translate a state of awareness that their initial opinions need to be rethought by taking into account several dimensions they were unaware of at the time of the pre-test.

The interest in the gene drive expressed by students at the beginning of the experiment did not change significantly towards the end of the experiment. Moreover, the majority of changes in the choice of interest class led to higher classes in terms of interest in gene drive, this indicates that the exposure of these students to controversies, risks and uncertainties related to the application of gene drive did not adversely affect their interest in the technoscience discussed. These results could be explained by the fact that up to now, in the Tunisian university context, science education is done in the light of the positivist approach that values scientific results, exalts stabilized knowledge and rules out any questioning of scientific applications. Placed under the influence of such an approach to teaching, these students would have developed a mechanism for systematic valorizing all knowledge and/ or scientific application.

CONCLUSION

The disruptive and multidimensional issues generated by the development of technoscience make it necessary to teach socially acute questions, which presupposes a challenge, even partial, to customary pedagogical and didactic practices. It is in this perspective that we designed a teaching device, which aims to use a global and interdisciplinary approach to address the concepts of uncertainty and risk, related to technoscience, by helping to build reasoned opinions about SAQ and by focusing on the development of futures thinking. The results of this study show that such a device has a positive impact on the acquisition of scientific knowledge and that it supports the construction of a reasoned opinion. This study also shows that these students have undergone a kind of conditioning that has made them rigid in the face of any critical thinking on knowledge or scientific applications and in the perspective of overcoming this resistance it would be appropriate to amplify and diversify scientific learning approaches.

The main extension of this research consists in analyzing the future scenarios built by the students, as well as the texts of opinions formulated at the end of the scheme in order to reveal other dimensions that would highlight the potential contribution of such a device in favor of an education for the future.

REFERENCES

Ameline, S., & Levannier, M. (2021). Santé environnementale et risques sanitaires. In *DEAS* (pp. 45-54). Vuibert. https://stm-cairn-info.gorgone.univ-toulouse.fr/deas--9782311660791-page-45.

Barelli, E. (2022). Imagining the school of the future through computational simulations : Scenarios' sustainability and agency as keywords. *Frontiers in Education*, *7*, 897582. https://doi.org/10.3389/feduc.2022.897582.

Bensaude-Vincent, B., Loeve, S., Nordmann, A., & Schwarz, A. (2011). Matters of interest: The objects of research in Science and Technoscience. *Journal for General Philosophy of Science*, *42*(2), 365-383. https://doi.org/10.1007/s10838-011-9172-y.

Buntting, C., & Jones, A. (2015). Futures thinking in the future of Science Education. In *The Future in Learning Science: What's in it for the Learner?* (pp. 229-244). https://doi.org/10.1007/978-3-319-16543-1_12.

Chauvigné, C., & Fabre, M. (2021). Questions socialement vives : Quelles approches possibles en milieu scolaire ? *Carrefours de l'Éducation*, *52*(2), 15-31. https://doi.org/10.3917/cdle.052.0011.

Chneiweiss, H. (2017). Pour un groupe international d'experts du génome, GIEG, équivalent du GIEC. *Archives de philosophie du droit*, *59*(1), 17-30. https://doi.org/10.3917/apd.591.0054.

Courtier-Orgogozo, V. (2019). Le forçage génétique (gène drive) et ses applications. *Bulletin de l'Académie Vétérinaire de France*, *172*(1), 94-98. https://doi.org/10.4267/2042/70673.

Covitt, B. A., & Anderson, C. W. (2022). Untangling trustworthiness and uncertainty in Science: Implications for Science Education. *Science & Education*, *31*(5), 1155-1180. https://doi.org/10.1007/s11191-022-00322-6.

Daniels, J. D., Radebaugh, L. H., & Sullivan, D. P. (Eds). (2018). *International business: Environments & operations* (Sixteenth edition). Pearson.

Fleury-Bahi, G. (2010). L'évaluation du risque environnemental. In *Des concepts aux applications* (pp. 59-71). De Boeck Supérieur. https://shs-cairn-info.gorgone.univ-toulouse.fr/psychologie-et-environnement--9782804162566-page-59.

Hervé N., Panissal N., Schouver F. & Gueziec C. (2021). Développer la pensée prospective ? *Recherches & Éducations*, *23*. https://doi.org/10.4000/rechercheseducations.11878.

Jones, A., Buntting, C., Hipkins, R., McKim, A., Conner, L., & Saunders, K. (2012). Developing students' futures thinking in Science Education. *Research in Science Education*, *42*(4), 687-708. https://doi.org/10.1007/s11165-011-9214-9.

Kermisch, C. (2012). Vers une définition multidimensionnelle du risque. *VertigO - la revue électronique en sciences de l'environnement*, *12*(2). https://doi.org/10.4000/vertigo.12214.

Laganier, R., Veyret, Y., Gache, M.-L., & Noaille, J.-M. (2023). Risques et crises technologiques. In *Atlas des risques et des crises* (pp. 22-23). Autrement. https://shs-cairn-info.gorgone.univ-toulouse.fr/atlas-des-risques-et-des-crises--9782080283511-page-22.

Lange, J.-M., Victor, P., & Trouvé Alain. (2007). *Expression d'une opinion raisonnée dans les éducations à… : Quels indicateurs ? AECSE, Strasbourg, France.* <hal-02463734>.

Lefeuvre-Halftermeyer, A., Govaere, V., Antoine, J.-Y., Allegre, W., Pouplin, S., Departe, J.-P., Slimani, S., & Spagnulo, A. (2017). *Typologie des risques pour une analyse éthique de l'impact des technologies du TAL*. https://doi.org/hal-01501192.

Legros, M., M. Marshall, J., Macfadyen, S., R. Hayes, K., Sheppard, A., & G. Barrett, L. (2021). *Gene drive strategies of pest control in agricultural systems: Challenges and opportunities*. *14*(9), 2154-2332. https://doi.org/10.1111/eva.13285.

Mansouri, A., & Collombat, P. (2020). CRISPR/Cas9, un ciseau moléculaire pour l'étude des cellules ß-pancréatiques. *Médecine des Maladies Métaboliques*, *14*(8), 738-743. https://doi.org/10.1016/j.mmm.2020.10.001.

Morin, O. (2018). Problématiser et… re-problématiser les QSVE ; vers une démarche d'enquête structurée par la rencontre de rationalités. In *Agora* (pp. 43-64). Éducagri éditions. https://doi.org/10.3917/edagri.simon.2018.01.0043.

Nedelec, L. (2018). *L'éducation aux sciences dans un monde incertain : Comment les enseignantes appréhendent-elles les incertitudes de la question vive de la transition agroécologique? Étude de cas auprès d'enseignantes de l'éducation nationale et de l'enseignement agricole en contextes de formation*. https://theses.hal.science/tel-02409080v1.

Nedelec, L., & Molinatti, G. (2018). Démarche d'enquête et éducation aux incertitudes : le dispositif des scénarios du futur. In J. Simonneaux (Ed.), *La démarche d'enquête : Une contribution à la didactique des questions socialement vives* (pp. 165-184). Éducagri éditions. https://doi.org/10.3917/edagri.simon.2018.01.

Panissal, N., & Plégat-Soutjis, F. (2018). Quels savoirs pour l'éducation à l'éthique de l'ingénierie génomique : le cas du forçage génétique. In J. Simonneaux (Ed.), *La démarche d'enquête : Une contribution à la didactique des questions socialement vives* (pp. 143-164). Éducagri éditions.

Saoudi, H., & Bouamoud, H. (2024). Apprehension of technosciences and initiation to education for uncertainty: Case of gene drive. In D. Elomari (Ed.), *Qualitative approaches to pedagogical engineering* (pp. 71-93). IGI Global.

Schenk, L., Hamza, K., Arvanitis, L., Lundegård, I., Wojcik, A., & Haglund, K. (2021). Socioscientific issues in Science Education: An opportunity to incorporate education about risk and Risk Analysis? *Risk Analysis*, *41*(12), 2209-2219. https://doi.org/10.1111/risa.13737.

Simonneaux, L. (2003). L'argumentation dans les débats en classe sur une technoscience controversée. *Aster*, *37*(1), 189-214. https://doi.org/10.4267/2042/8825.

Wedell, N., Price, T. A. R., & Lindholm, A. K. (2019). Gene drive: Progress and prospects. *Proceedings of the Royal Society B: Biological Sciences*, *286*(1917), 20192709. https://doi.org/10.1098/rspb.2019.2709