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Imagining the School of the Future Through Computational Simulations: Scenarios' Sustainability and Agency as Keywords

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Computational simulations are fundamental tools not only for scientific research but also for education. They are frequently used as virtual laboratories to foster students' understanding of the theoretical concepts that lie at the basis of the simulated systems. Recent research works in STEM education have started to explore the potential of simulations as future-oriented objects, to support students in the development of future scenarios for real-world situations. In this paper, we present a teaching-learning module targeted to upper high-school students on simulations of complex systems. The peculiarity of this course is that, guiding the students through the conceptual and epistemological analysis of some computational agent-based models, we were able to ground on these disciplinary bases the introduction of key concepts of the futures studies, like that of scenario. More specifically, in this paper we address an original future-oriented activity in which the students were required to choose an urgent problem of their interest, imagine possible and desirable scenarios based on a simulation and identify the sequence of actions to be undertaken to reach the preferable future. In presenting the results of the module's implementation we focus on two groups of students who spontaneously decided to address a problem related to the current educational system. In particular, we discuss how the future-oriented activity based on simulations led the students (i) to imagine sustainable scenarios for the school of the future, in which a dynamical equilibrium between opposite tensions is achieved, without any of them being eliminated and (ii) to recognize themselves as agents of transformation in a public, professional, and personal dimension.

Keywords: simulations, future scenarios, agency, equilibrium, future-oriented science education, school

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INTRODUCTION

It was almost seventy years ago that computational simulations entered the realm of scientific methods. In these frightening times, it is impressive to recall that these techniques were first developed for military purposes, in the research context that led to the nuclear bomb in Los Alamos (Galison, 1996). Following World War II, the range of disciplinary fields in which simulations started being used has been expanding until nowadays, when it is almost impossible to name any discipline that has not used or developed computational tools and simulations to advance its research (Borrelli and Wellmann, 2019). In all these disciplines, simulations are used for different scopes among those one very common is that of prediction i.e., the elaboration of possible future scenarios for a target system based on the behavior of the simulated one (Grüne-Yanoff and Weirich, 2010).

Computational simulations are not only fundamental pillars of scientific research: they have become important instruments also for education, as they are frequently used as virtual laboratories to foster students' understanding of the theoretical concepts that lie at the basis of the simulated systems. Even if simulations have been used for teaching-learning purposes for decades at many levels, educational research has rarely focused on the use of simulations to obtain future scenarios, but rather has investigated their role in formulating explanations or the difficulties encountered by novices in interpreting these types of models of complex systems (Jacobson and Wilensky, 2006; Hmelo-Silver et al., 2014).

Supported by the recent body of literature in future-oriented science education, our hypothesis is that computational simulations, if adequately exploited in STEM teaching, can become laboratories to imagine possible scenarios for real complex systems, with the potential to stimulate students' reflections on the future. Moreover, we believe that by using in teaching activities a specific category of simulations, named *agent-based simulations*, students can be guided not only to envision a plurality of scenarios but also to find spaces of action in the present to contribute themselves to the realization of their desirable futures. Indeed, agent-based simulations show that the evolution of a system strongly depends on the rules that regulate the interactions among the individual components of the model, and the introduction of different local rules can lead to a range of global behaviors. In our approach, the simulations are not meant to predict the future perfectly or produce realistic pictures of it. Guiding the students to recognize conceptual and epistemological details of computational simulations, the aim is rather to construct disciplinary lenses to prepare the students to look at the future in a new way. Indeed, students are led to explore the mechanisms to build a plurality of different scenarios using these tools, hence enhancing their imagination of their personal future and the future of cities, countries, and society, and become responsible agents and citizens able to navigate the complexity of time (Barelli, 2022).

In the paper, we will present the design and implementation of an innovative teaching-learning activity of scenario construction based on simulations, within an 18-h module targeted to upper-high school students on the topic of computational simulations of complex systems. The article is structured as follows.

In the framework, after introducing the educational potential of agent-based simulations through an overview on the literature in STEM education, we introduce concepts of the discipline of future studies with a specific focus on the concept of scenario and present examples of previous future-oriented activities that framed these concepts within an educational perspective, as well as research results about the participants' reactions to this kind of activities. The next part of the framework is centered on the specific role of simulations to construct future scenarios and on the possible connections that can be established between agent-based simulations and the concept of agency. The elements introduced in the framework will lead to the statement of six design principles at the basis of our original future-oriented activity which is the object of the following section. The paper continues with the description of the module and of the future-oriented activity, providing details on the implementation, the participants, and the data collection tools. In the following section, we describe the methodology of thematic data analysis conducted to answer two research questions. The same two-pronged structure will be followed to present the findings and discuss them.

FRAMEWORK: FROM THEORETICAL FRAMEWORK AND RESEARCH BACKGROUND TO DESIGN PRINCIPLES

The Educational Potential of Agent-Based Simulations: Overview on the Literature in STEM Education

Within the wide set of simulation tools that nowadays are used as a pillar of the scientific method, two main categories can be distinguished (Grüne-Yanoff and Weirich, 2010): the equation-based and agent-based ones. In the former case, the evolution of a target system is described by differential equations; once they are numerically solved, they allow to determine the future state of the system starting from the present state. On the opposite, in agent-based simulations, the dynamics of the target system is generated making the individual agents evolve according to behavioural rules. Because of that, equation-based models and simulations are often claimed to have a *top-down* character while the agent-based ones are *bottom-up*. In science education, equation-based and agent-based simulations are mainly introduced when complex systems are addressed. In particular, they are used when the science complex system is emphasized as the discipline that studies how behaviour of phenomena at different scales is related to the interdependent components at lower scales (Bar-Yam, 2016). This should already recall the distinction between equation- and agent-based modelling addressed above in terms of their top-down vs bottom-up nature.

Equation-based and agent-based models and simulations have also become a way within educational research to address in teaching different forms of reasoning about dynamic systems, with special regard to the formulation of explanations (Jacobson and Wilensky, 2006). The first form of reasoning is positioned on a "macro" level: the focus is on the system conceived as a population (sometimes as composed of different groups) with its own macroscopic properties that evolve over time according to rates of change, for example of transitions between groups. On the contrary, the second form of reasoning acts at a "micro" level: the attention is on the minimum elements of the system, the agents, which interact according to local rules.

Traditional mathematical and science education mainly encourage aggregate reasoning, also through the introduction of differential equations as descriptive tools of dynamic systems. More recently, since the 90s, importance of agent-based reasoning has been emphasized within education to foster understanding on the systems and to enter the mechanistic dimension of local interactions (Wilensky and Reisman, 2006) that has been found to be a relevant component of students' sensemaking about phenomena (Kapon, 2016). Nowadays, the two forms of reasoning are considered both essential to reach a profound understanding of complex systems and to comprehend the emergence of global patterns and behaviours from the local interactions among agents. This concept has been expressed as the "embedded complementarity" of aggregate and agent-based reasoning (Stroup and Wilensky, 2014). Even if they have their own very different features, they are not incompatible, nor necessarily working against one other. On the opposite, they are complementary for reaching a mature reasoning about emergent phenomena in complex systems. Moreover, this complementarity is "embedded" because it requires not to consider the two forms of reasoning as juxtaposed, but to move from one to the other, in a dynamic mutual relationship where elements of connection can be pointed out. Several strategies can be found to connect aggregate and agent-based reasoning: Levy and Wilensky (2008) have identified relevant at this account the construction of mid-level groups, that are in-between the level of the agents and that of the emergent property. Barth-Cohen (2018) has instead focused on the role of transitional explanations between microscopic and macroscopic levels of the system.

Another significant body of research literature is focused on the effectiveness of programming environments to learn about the simulated systems and to develop abilities of computational thinking (Sengupta et al., 2013; Wilensky et al., 2014). For what concerns agent-based simulations, the most used platform for the use and development of simulations is NetLogo (Wilensky, 1999). It is not only a platform where simulations, from a wide range of diverse domains, are available to learners, but it is a "low threshold and no ceiling" programmable environment, in which the users can create their own models using a high-level language. In the module that is object of this paper, three simulations of the NetLogo Models Library were introduced to the students and built the basis for the future-oriented activity that they carried out.

The Concept of Scenarios From the Futures Studies to Future-Oriented Science Education

How has the field of future-oriented science education inherited many concepts coming from the fields of futures studies has been widely discussed in previous research works (Levrini et al., 2019). The very same distinction between certain predictions and a range of possible projections—graphically represented in the futures' cone (Hancock and Bezold, 1994; Voros, 2003)—is at the basis of conceiving the future as a plurality of probable, plausible, possible, and preferable scenarios. For the purposes of this paper, the concept of scenario deserves to be discussed in more detail.

Scenarios are the methods of choice in the discipline of futures studies and can be defined as descriptions of possible future situations including the paths of development which may lead to these situations (Kosow and Gaßner, 2008). Far from aiming at achieving a comprehensive image of the future, the development of a scenario relies on the selection of key factors that are considered important for the future time horizon imagined. To obtain future scenarios, several techniques can be used separately or in combination (Börjeson et al., 2006). Kosow and Gaßner (2008) identify three main families of methods:

- Trend extrapolation: the scenario is constructed based on trends that already exist in the present or have existed in the past. These trends are "projected" into the future by quantitative analyses or qualitative methods. A typical scenario that can be obtained by trend extrapolation is the so- called "business as usual" which is the most probable future in case nothing changes with respect to the current situation; it is often used as a reference scenario against which other scenarios are compared.
- Systematic-formalized techniques: to this family belong all the scenario methods grounded on the definition and mutual combination of key factors for the system's evolution. These methods are named "systemic-formalized" in contrast with more "intuitive" techniques (Heinecke, 2006, p. 187). Examples are the impact analysis, the consistency analysis, and the cross-impact analysis that, in different ways, analyze quantitively the effect of a certain key factor on others, and the conditional probabilities for the events hypothesized.
- Creative-narrative techniques: as the name suggests, in this case, the focus is on the power of creativity and narrative development to construct visions of the future. Because of their emphasis on the elaboration of scenarios as communication and participatory process, they are often used in explorative phases of scenarios construction and in the development of the desirable futures.

If these three families of techniques are clearly disjointed, in practical contexts constructing scenarios is a hybrid process that integrates methods belonging to different families. It is the case of the modeling and simulation methods that will be discussed in the next paragraph.

From this overview on the concept of scenario from the futures studies' literature, we can sketch the first design principles at the basis of the design of the original future-oriented activity that we will present in the next section:

(DP1) Provide the opportunity for students to conceive the future as a plurality of scenarios rather than as the unique result of deterministic predictions.

(DP2) Present different types of futures, especially the possible and the desirable ones, and suggest the related methods for developing these scenarios.

(DP3) Introduce complementary ways for constructing scenarios, alternating the use of systematic-formalized and creative-narrative techniques.

As for futures studies, also future-oriented science education recognizes the centrality of the concept of scenario to foster students' engagement in imagining personal and societal futures. In particular, in experiences related to the

ISEE (https://www.iseeproject.eu/) and FEDORA (www.fedora-project.eu) projects, a bunch of activities have been designed to guide the students to construct possible or desirable scenarios for the future (Barelli, 2017; Barelli et al., 2018; Levrini et al., 2019, 2021; Barelli and Levrini, 2021). In some cases, they were required to individually write an essay to describe their ideal day twentyish years later; in others, they had to work in groups to identify a problem of the present and imagine a future in which this issue had been solved, highlighting possible actions to be undertaken to reach the preferable scenario. The reactions of the participants to this kind of activity have been studied. On one side the high potential of scenario-based reasoning has been emerging as a way to structure future thinking and develop so-called future-scaffolding skills (Levrini et al., 2021). However, criticalities have been arising too. If dystopian and pessimistic views are very common when students imagine the future—for a recent review of the literature we refer to the work by Rasa et al. (2022)—when they are asked to imagine a desirable scenario the result is often a picture of static, idealized stillness (Barelli, 2017). The request of dreaming about a preferable future triggered attitudes of detachment from reality that resulted in fictional, idealized scenarios that avoid any possible tension or conflict between interests or people. This made the scenarios totally unrealistic for the students (Levrini et al., 2021), violating in this way one of the main criteria that ensures the quality of a scenario: its *plausibility*, i.e., the belief in the fact that the possibilities of the developments presented in the scenarios *are* possible developments (Greeuw et al., 2000; Kosow and Gaßner, 2008). Therefore, the following phase of the activities in which the students had to identify possible actions became impoverished: being the future unrealistic and explicitly unsustainable, it is unfeasible, undoable, and unactionable.

The Role of Simulations to Construct Future Scenarios

The genesis of the idea of constructing scenarios to gain an understanding of the future dates to the 1950s when, after World War II, "the U.S. Air Force tried to imagine what its opponents might do and to prepare alternative strategies" (Mietzner and Reger, 2004, p. 48). Going beyond the military planning, it was in the early 1970s that the scenarios reached the general public with the publication of the highly contentious "The Limits to Growth" (Meadows et al., 1972). In this report, the members of the so-called Club of Rome drafted several future scenarios based on "World 3", a system dynamic simulation that accounted for the interactions between population, industrial growth, food production, and limits in the terrestrial ecosystem.

The role of simulations to develop scenarios is not only restricted to a historical circumstance but extends up to the present. Both equation- and agent-based models allow obtaining pictures of the future depending on initial conditions. In the case of equation-based models, differential equations are numerically integrated, while with agent-based approaches, the evolution of the system is generated by the actions and interactions among simulated individuals that follow specific behavioral rules (Grüne-Yanoff and Weirich, 2010). However, even if simulations are undoubtedly important tools in the process of scenario construction, the need for effective communication of their results has led to flank formal modeling activities with narrative techniques. For example, in the "Story-and-Simulation" approach, formalized by Alcamo (2001), a "storyline describes in story form how relevant events unfold in the future, while the model calculations complement the storyline by presenting numerical estimates of future environmental indicators and helping to maintain the consistency of the storyline" (p. 6). More than that, in such hybrid approaches, the benefit of combining simulations and narratives is mutual: the storyline usually helps identify the elements to be simulated, and the computational model allows refining, complementing, and giving validity to the narrative (Kosow and Gaßner, 2008, p. 84).

On these theoretical bases, other two design principles can be outlined, regarding the specific role of simulations to develop scenarios:

> (DP4) Value simulations (particularly agent-based ones) as tools to model a future-oriented issue and as virtual laboratories to obtain possible evolutions of the system.
> (DP5) Complement the imagination of the future scenario with the sketch of the related storyline including possible paths of development.

The Role of Simulations to Trigger Student Agency

Even if there is no global consensus on the definition of "student agency", a recent OECD report (OECD, 2019) puts this concept at the center of the 2030 Learning Compass framework. Here, the student agency is conceptualized as a rather general sense of responsibility that the students perceive as members of society who can influence other people, events, and circumstances for the better. The importance of developing students' awareness of their role as agents for their own future and for that of society is widely recognized, but the discussion on how science education can contribute to this objective remains open (Barton and Tan, 2010; Arnold and Clarke, 2013; Stroupe, 2014; Sjöström and Eilks, 2018). In the following we will focus on the potential of computational simulations, specifically of agent-based ones, to foster students' reflection on their agency and transformational role.

As we anticipated in the previous paragraph, agent-based simulations are a type of model in which the components of the modeled system interact with each other according to some behavioral rules. The so-called *agents* have some features, receive instructions from the programmers, and, following them, generate the evolution of the system. For example, it happens that agents that can be orange or blue, randomly arranged on a bi-dimensional grid, following rules like "if more than 70% of your neighbors are of a different color, randomly move to an empty cell", create a situation in which blocks of agents of the same color are separated (Schelling, 1971). This approach to modeling strongly differs from more "traditional" methods based on the resolution of equations. While with equation-based models the system is modeled as an undifferentiated whole and its behavior is estimated only at the macroscopic level, for agent-based simulations the discrete minimum components are emphasized, and their local interactions lead to emergent phenomena observed by the macroscopic behaviors at the aggregate level. Moreover, while equation-based simulations are deterministic, the agent-based counterparts generate different temporal evolutions every time they are executed because of the stochastic character of the behavioral rules (Barelli, 2022). These differences between the two approaches make agent-based simulations particularly well-positioned to trigger reflections on student agency. Firstly, they show how the role of the individual is essential to produce a global behavior. At the back of an evolving system and a scenario reached, there is a multitude of individuals that have carried out specific actions. Secondly, agent-based models allow us to highlight that the actions taken by the agents are in fact *inter*actions between agents and their neighbors. Finally, the stochastic feature of the model resembles the unpredictability of the effects of given causes in complex systems.

The last design principle aims to exploit in the future-oriented activity the role of student agency:

> (DP6) Give to the students the possibility to make students think at themselves as protagonists of the paths of development toward the desirable scenario.

CONTEXT AND SAMPLE

The Future-Oriented Module on Computational Simulations

The context in which we conducted the study object of this paper is a teaching-learning module on simulations of complex systems that was implemented in January-February 2021 as part of the program of the Department of Physics and Astronomy of the University of Bologna, Italy for university orientation of high school students. It was implemented in six lessons of 3 h and was articulated in five activities whose main goals are summarized in **Table 1**. For a detailed description of the module, we refer to its extended analysis in Barelli (2022).

Since in this paper we will focus on the results of students engaging with the future-oriented activity, we provide some more details about the last part of the module. The students were divided into groups and were asked to address different tasks. The first task consisted of the identification of a real-world problem of students' interest, followed by the request to explore possible future scenarios based on a NetLogo agent-based simulation that they considered suitable to address the topic. Then, they were asked to imagine a desirable scenario and to engage in a back-casting procedure, identifying the actions, decisions, policies, and contingencies which have made it possible to realize the ideal future in 2040. To exploit the role of individual agency in the imagination of the future, in this phase the students were required to make explicit which role they had in the path of changes from the present to the future they foresaw, as professionals, members of society, and as individuals in general. To summarize their work, the students had to prepare a presentation about their story of success. The structure of the activity was borrowed from similar ones previously implemented within the I SEE project and described by Levrini and colleagues (2021). The novelty of this one consists in the fact that to imagine the possible future scenarios, the students were asked to rely on a NetLogo simulation of their choice.

The Participants

More than 50 students voluntarily applied and 35 of them (25 males and 10 females) were selected for participation in the course. The criteria of selection were established by the overall organization of the orientation initiative and aimed at avoiding the presence of more than 5 students from the same class and guaranteeing the gender balance as more as possible. All students attended the third or fourth year of a dozen of secondary schools in Emilia-Romagna (Italy). The majority (30 out of 35) attended a "scientific lyceum", a type of high school centered on scientific subjects; three students came from a "classical lyceum," which is focused on teaching-learning humanities and ancient languages; two students attended a technical-aeronautic institute. The students took part at most of the activities of the course; only one participant abandoned the course after one lesson. For the group activities, the instructors arranged in advance seven teams of five students each to avoid as much as possible the presence of more students of the same class in the same group and guarantee the presence of at least one female student in each group.

Tools of Data Collection

Several data were collected during the module's implementation using individual questionnaires, shared digital boards, sheets and presentations produced by group works, collective discussions, video-recordings of lectures, group works, and interviews. For the analysis this paper is focused on we considered the video recordings of (i) the final presentations of the seven groups of students at the end of the future-oriented activity described above and of (ii) the collective discussion that followed the groups' presentations. Before being analyzed the data were transcribed and anonymized. The names of the students were replaced by pseudonyms to keep the reference only to the students' gender.

RESEARCH QUESTIONS AND METHODOLOGY

In this paper we address the following research questions.

1) How do the students construct their desirable futures using agent-based simulations?
2) What kind of issues are touched by the students when they describe the current problems of school, their ideal future, and the priorities for its transformation? What is the role of students and teachers' agency in the process of transformation envisioned?

To address RQ1, the first step consisted in analyzing the video recordings of the seven groups' presentations. In particular, we were interested in finding common features of the desirable scenarios imagined by the students, across the huge variety

TABLE 1 | Articulation of the module on simulations of complex systems and the main goals of each activity.

Title of the activity	Main goals
Lectio magistralis: "Computational physics in the era of big data"	- To situate the simulations in the wider panorama of the computational physics as the third pillar of contemporary scientific research
Roundtable with early career researchers: "Simulations as research tools"	- To show different research contexts in which simulations are used or developed by physicists - To enrich students' imagination about the frontiers of physics research and orient them to the university choice
Interactive analysis of agent-based simulations of complex systems	- To show the differences between equation- and agent-based models - To make students experience first-hand NetLogo agent-based simulations that embed different interaction's dynamics i.e., the predator-prey mechanism, the opinion dynamics, and the cooperative behaviours
Activity of analogies' development: "From models of systems to real problems"	- To guide the students to extend the three agent-based models learnt during the previous activity to other real-world problems
Future-oriented group activity of scenarios' construction based on simulations	- To exploit the role of agent-based simulations to construct possible, probable, and desirable scenarios for real-world problems

of the issues chosen. Comparing the presentations of the seven groups, we found that a recurrent theme in many desirable scenarios was the concept of equilibrium. After having identified this main feature, we focused on analyzing how the different groups embedded an aspect of balance in their desirable scenarios, and how the work on the agent-based simulations allowed them to make it explicit. In the second phase, we analyzed the video recording of the final collective discussion, when students were guided by the instructors to reason about the types of scenarios identified. In this way, we checked whether the students were aware of the peculiarity of the scenarios of equilibrium to produce reliable future scenarios.

Differently than RQ1, RQ2 is a question related to a specific issue imagined by the students i.e., the school, so we could not consider all the groups' presentations as a dataset: we had to focus just on the presentations of the two groups that, in the future-oriented activity, decided to address a problem related to school (Group 4 and 7). To identify the main features of the students' ideal school in the future, we chose thematic analysis (Braun and Clarke, 2006) as the qualitative method "for exploring and interpreting patterned meaning" in our dataset (Braun and Clarke, 2022). We proceeded following the process of the so-called reflexive approach to thematic analysis that envisions a recursive engagement with the data to produce a robust analysis, despite the non-theoretical orientation of the method (Braun and Clarke, 2006). The main phases that Braun and Clarke (2022) delineate for reflexive data analysis are: (1) familiarization with the dataset, (2) coding, (3) generation of initial themes, (4) development and review of themes, (5) refinement, definition, and naming of themes, (6) writing and contextualization within the literature. In the following paragraphs, we describe how we operationally addressed these phases.

According to the methodological prescriptions, after having listened the presentations and read the transcripts multiple times (*familiarization with the dataset*), we arranged a preliminary organization of the dataset into an Excel grid in which each row corresponded to a sentence of the transcript (i.e., a text's excerpts ending with a period).

The second phase, that Braun and Clarke name the *coding* phase, consisted in adding columns to the Excel grid in order to write the bottom-up tags that corresponded to each excerpt. In this bottom-up process, the words or expressions used as codes were strictly connected to students' words. For example, a sentence like:

> *A source of stress, as we know, for all students is the final result of that path, that is the final exam and we currently know how the exam tests greatly influence the final evaluation and therefore we decided to favor more the path that is carried out in all school years compared to evaluating only the final exam. (Group 7)*

was coded with "cause of stress," "final exam" (in Italian: "maturità"), and "enhancement of the whole study path."

The bottom-up coding of the transcripts of the two groups' presentations was followed by the third methodological phase in which the codes were organized in categories, namely the themes (*generation of initial themes*). Operationally, the codes written were listed and grouped in 10 themes, as reported in **Figure 1** (bottom right). For example codes referring to students' way to deal with time for study, hobbies, and relax ("management of time," "time for themselves"), to the hours dedicated to school and study ("school in the afternoon," "less autonomous study"), or to the time needed for understanding ("same amount of information but more diluted") were all colored in light blue and grouped in a theme concerning the relationship between routine and time management ("school determines routine and time management"). It can be noticed that for the first two themes, two colors have been used. Indeed, the students talked about technological innovations and marks-provoked anxiety in two different ways. Regarding technology, they wish for the use of more technological devices (darker yellow) but at the same time recognize the need to keep something on paper (lighter yellow). The same concerns anxiety: on one side they feel enormous stress caused by marks and evaluation processes (darker green) but on the other, they recognize the importance of forms of evaluation to keep students motivated. We remark that the passage from the codes to the themes was for us a delicate methodological step since it required passing from something that was anchored to the specific set of raw data to more general categories that found

Bottom-up codes - Group 4			
Problem	Teaching method		
Problem	Marks		
Technology	Solution to boredom		
Technology	Needs raised by the pandemic	Flank the paper books	
Source of difficulties	Marks	Passage from numbers to letters	
Technology	Pandemic as the trigger for change	Risks and benefits	
Technology	Help to students from the teachers		
Management of time	Teaching method	Same amount of information but more diluted	
Management of time	School in the afternoon	Tutoring with professors	Less autonomous study
Orientation	Career	Discover attitudes	
Physical activity			
Dialogue students-teachers	Relationship	Humanization of the teacher	
Trips	Internships	Knowledge more various	
Funding			
Routine	Rest		
Applied knowledge			
Routine	Time at school	Sport	Laboratories
School as care for relationships			
Time for themselves	Routine		
Government	Top-down intervention		
Agency students and teachers	Petitions	Movements on social network	
Experimenting change			
Teachers as protagonists of change			
Peer instruction			
Students agency			

Bottom-up codes - Group 7			
Problem	Stress		
Changes and not changes			
Cause of stress	Final exam	Enahnacement of the study path	
Cause of stress	Tests	Organization between students and teachers	
Technological investments	Resource		
Prevention of bullying			
Marks as push	Resource		
Keeping paper books	Resource		
PCTO to apply knowledge	Resource		
Pandemic	Reach awareness on the situation of school		
Protests	Students agency	Pandemic	
Dialogue institutions-students	Innovation	Pandemic	
Agency	Public dimension	Protests	Dialogue students-professors
Agency	Personal routine dimension	Do one's own work	

FIGURE 1 | Grouping of the bottom-up codes in themes.

confirmation also in the sociological or educational literature or in the findings from previous studies.

The fourth and fifth Braun and Clark's phases regard the *review, refinement, and naming of themes*. The main criteria we chose were: (i) grouping "similar themes" to avoid redundancies, (ii) formulating the macro-themes in a way to address the RQ, and (iii) keeping firmly distinguished from the other themes the issues concerning students and teachers' agency. If the first and second criteria are rather transversal to the thematic analysis as a methodological process, the second is more specific for our study, since it allows to address the second part of RQ2 (*What is the role of students and teachers' agency in the process of transformation envisioned?*). The output of this stage of themes review was the list of the seven macro-themes in **Figure 2** that we will illustrate in depth in the analysis section. Here, we briefly comment, with some examples, on the adherence of the process to obtain macro-themes with respect to the aforementioned criteria. First of all, we noticed that, for the role they had in the story we wanted to tell with our analysis, some themes overlapped. It was the case of "application of knowledge for the future career" and "trade knowledge" that we grouped in only one macro-theme referring to the need of rethinking knowledge's organization at school. The same happened for the macro-theme related to agency that summarizes three themes ("agency in a public dimension," "agency in a private dimension," and "school as an institution"). To comply with the third criterion, this macro-theme was kept separated with the others, especially to that of pandemic with which some superpositions were observed (e.g., the role of students' demonstrations during the pandemic can be interpreted as a manifestation of agency too). Finally, according to the second criterion, all the macro-themes were named in order to outline the problems of the present, needs, dreams for the future, and priorities of transformation; indeed, we have "the problem of. . .," "the role of. . .," "the dream of. . .," "the hope for. . .," "the priority of. . .".

Once the macro-themes were identified, preparing to the last phase of *narrating the results*, we looked again at the transcripts and improved the division in paragraphs according to two criteria. First of all, different phases of the activity (introduction, statement of the problem, introduction of the simulation, explications of the scenarios obtained with the simulation, presentation of the ideal future, and back-casting) could not be mixed in the same cell. Secondly, in each excerpt, only one macro-theme should have appeared. At this point, we counted the number of words in each text excerpt to have a measure of its length and adjusted the height of the row accordingly. In this way, we were able to obtain a visualization of how the two groups' presentations were articulated in macro-themes and what was the relative frequency of each macro-theme with respect to the total coded part of the transcripts.

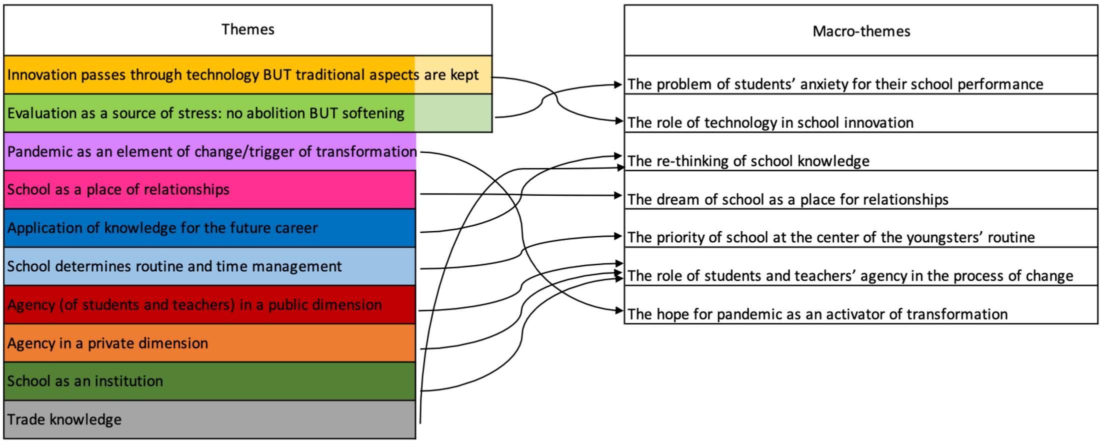

FIGURE 2 | Grouping of the themes in macro-themes.

To validate the analysis, in line with recommended practices (Anfara et al., 2002), the coding procedure was triangulated through peer debriefing with researchers in STEM education during specifically designed meetings. In particular, the richness of research sensitivities allowed to reach the set of macro-themes presented and the connections with the literature and the key issues of sustainability and agency.

DATA ANALYSIS AND RESULTS

Before presenting the results of the data analysis we provide an overview of the presentation of the seven groups. In **Table 2** we write, for each group, a short description of the problems chosen, the simulations used to tackle these issues, the scenarios identified, and the main features of the desirable futures obtained.

The Construction of Scenarios of Equilibrium for Complex Societal Issues

As summarized in **Table 2**, in the future-oriented activity, 5 groups out of 7 (groups 2, 3, 4, 5, and 7) imagined their preferred scenarios as strongly characterized by an idea of equilibrium. This equilibrium was interpreted in a different way by the groups.

Group 2 worked on the problem of overpopulation and, after having explored scenarios in which the population ran out of resources or was threatened by infectious diseases, imagined a scenario by interpolating the two extremes previously identified. Observing the graphics provided by the simulation, they noticed that a situation of equilibrium between resources and humans was achieved when the curve reached a plateau (they call it a "stable peak").

Group 3 addressed the issue of globalization and imagined a future with a diversity of cultures that live peacefully, side by side, avoiding that only one culture takes the lead on everyone. Even if the idea of a peaceful co-living of cultures, without any conflicts or cultural predominance could suggest the idea of a "fake equilibrium" as the "equilibrium of perfection", the context in which this scenario was formulated contradicts this interpretation. Indeed, when the students outlined the story that led to that future, they considered many conflicting interests and a diversity of stakeholders which continue to co-exist in the final un-globalized scenario.

The problems chosen by Group 4 were related to the school system: the predominance of antiquate teaching methods and the stress experienced by students. They imagined three main stakeholders for their futures: supporters of traditional educational methods, supporters of innovative methods, and students. After having outlined two extreme scenarios (only educational methods or only traditional ones are used in the schools), they think of a future in which it is reached an equilibrium between old and new teaching methods where each of them works as a counterweight for the other and only their mutual presence can guarantee the realization of the students' objectives.

Group 5 worked on the problem of air pollution in the Po Valley (Italy). They explored different scenarios, including the business-as-usual and the worst-case scenarios, evaluating them based on the graph of pollution in time. Having realized that it is very difficult to make pollution lower, they changed the parameters until they reached a plateau of the curve which they considered their desirable future. In this case, the idea of equilibrium consists in the fact that the plateau is reached through the balance of two factors i.e., the number of polluting agents (e.g., factories) and the trees planted.

Group 7 addressed the problem of the high levels of stress that the students experience today because of the school system. Even in this case, they formulated their desirable scenario "between" two extremes: the elimination of the students that are psychologically defeated by the stress and the absence of any obstacle for students. The desirable equilibrium between stress and students is recognized by the group in the periodic evolution of the graph displayed by the simulation.

On the opposite, the two groups that did not cite any equilibrium in their analysis ended up with naïve scenarios that did not seem plausible either to the students. For example, Group 6 worked on the problem of ethnocentrism and imagined a future

TABLE 2 | Summary of the problems addressed by the seven groups in their presentation, the simulations used, the scenarios envisioned, and the actions to be taken.

	Group 1	Group 2	Group 3
Problem	Unfair distribution of wealth and resources in the world	Overpopulation	Globalization and cultural flattening
Simulation	Cash flow	Wolf sheep predation	Voting (extended)
Scenarios	Wide rich-poor gap Increase of middle class 3) Increase of middle class and decrease of poor	Depletion of resources and death of population Spread of diseases and death of population	Complete globalization and cultural flattening Partial globalization with survival of cultural islands 3) Equilibrium among cultures without conflicts nor cultural predominance
Desirable future	Few poor people, many middle-class people	Stable peak of population	Equilibrium
Actions	Creation and strengthening of a central bank institute	International agreements and norms for sustainable development	Revolution, internet

	Group 4	Group 5	Group 6	Group 7
Problem	Predominance of antiquate teaching methods and stress experienced by students	Pollution in the Po Valley (Italy)	Racial discrimination	High levels of stress experienced by the students because of the school system
Simulation	Cooperation	Urban Suite—Pollution	Ethnocentrism; segregation	Wolf sheep predation
Scenarios	Equilibrium between traditional and innovative methods Predominance of innovative methods 3) Predominance of traditional methods	Increase of pollution and stop after 20 years Constant increase of pollution 3) Reach of a plateau and slight decrease of pollution	Return to nationalisms Business as usual 3) Elimination of races from the public discourse	Stress wins Students win 3) Equilibrium
Desirable future	Equilibrium	Plateau	Elimination of races from the public discourse	Equilibrium between stress and students
Actions	Mass movements, peer instruction, individual will	Use of technologies, unification of factories, incentives for sustainable development	Improvements in education and institutional actions	Public demonstrations, lobbying and personal hard work

in which no relevance is given to race in the society and no discriminations exist at all. But after their description of this ideal scenario, a student talks about it as a "utopian scenario" and then says it is "unreachable". Hence, it seems that the construction of desirable scenarios based on equilibrium produced more realistic scenarios that the students believed more feasible than "too perfect" futures that resulted to seem utopian because clearly far from a sense of reality.

Students' awareness about the types of equilibrium embedded in their scenario emerged in the last discussion of the course:

> *Instructor: Can you tell us something about the concept of scenario? And on the scenarios that you all have identified, on the type of scenarios you have used. You've all used a very similar strategy to think about scenarios.*
> *F15 (Group 3): Probably at least as far as my group is concerned, first of all, we took our ideal scenario and that had to be there. . . How I wish it were... even utopian, even if it was not feasible. And then the opposite scenario probably comes automatically in the sense that I have my utopian scenario and then if everything goes wrong, everything completely wrong what could happen, right? And then an in-between scenario, that is. . . what I want is not achieved, but neither it is possible to reach the most absolute catastrophe. At least, we have reasoned that way.*
> *M8 (Group 2): For group 2 on overpopulation. . . for scenarios 1 and 2 we took extreme cases. Even in the simulations, to try to have an obvious result, we exaggerated parameters so as to obtain results that were certainly as we expected. Then instead for the third simulation which was the one that we preferred and was a little more balanced. . .*
> *Instructor: This is the other word you have all used. An equilibrium that is not a thermodynamic equilibrium, but a particular equilibrium. . . Which equilibrium? It is a form of equilibrium that you have all identified. . . Which form of equilibrium? What does balance mean in these situations?*
> *M13 (Group 3): Well, it is a balance of a system that is not a physical system but also often a social one and which, however, reaches its own equilibrium and stops varying...*
> *Instructor: It stops varying in what sense? Is it all dead?*
> *M13 (Group 3): No, I mean. . . Oh my God. . . (laughs) It depends on the case.*
> *Instructor: At the extremes, yes, because we arrive at a balance where everything stops.*
> *M13 (Group 3): No well it depends on the circumstances... (laughs) defining it dead is perhaps a bit exaggerated but basically, yes, you get to a situation that then persists.*

Instructor: But what is it that allows the balance to persist? What's this? What persists?
F17 (Group 4): Actually, in my opinion, a balance will be reached that can be defined as dynamic, that is, hybrid. Now it makes me think of chemistry right away... but this balance, however, does not persist. Well as we saw in the Voting simulations... it is not fixed... more or less the parts are those, but it is a continuous change, a continuous movement.

Triggered by a question from the instructor ("Can you tell us something about the concept of scenario?"), four students reacted by explaining how in the groups they constructed their scenarios. F15 is the first to take the floor saying that the desirable future identified by her group (Group 3) was "an in-between scenario". Indeed, they started from two extremes, the utopian ideal scenario, and its opposite, the worst-case scenario. Between these two extremes, they found the desirable future where "what I want is not achieved, but neither it is possible to reach the most absolute catastrophe". A similar strategy, which starts from the extreme cases, is followed by Group 2, as M8 tells. He emphasizes the role of the simulation in defining these extremes: "to try to have an obvious result, we exaggerated parameters so as to obtain results that were certainly as we expected". Hence, extreme scenarios originate from extreme values of parameters, that lead to configurations of the system that are easy to interpret. When the extremes are clear, it can be identified an intermediate scenario that is "a little more balanced". This is the first time that in the discussion the word "balance" appears explicitly.

Then, citing the difference between this kind of balance with respect to the thermodynamic equilibrium, the instructor presses the students to focus better on the type of balance embedded in the scenarios ("Which form of equilibrium? What does balance mean in these situations?"). Here we have a little exchange of words between the instructor and two students from two different groups who have two very different ideas of equilibrium. The first student, M13, from Group 3, does not seem to have grasped the idea of thermodynamic equilibrium expressed by the instructor, indeed he says the equilibrium does not necessarily regard a physical system but a social one ("it is a balance of a system that is not a physical system but also often a social one"). Beyond this difference, he describes the equilibrium as something that is "reached" by the system and consists of the fact that the system itself "stops varying". Pressed by the instructor ("It stops varying in what sense? Is it all dead?"), M13 confirms that "it depends on the circumstances" but, anyhow, "you get to a situation that then persists". If his idea can be ascribed to a conception of *static equilibrium*, F17, from Group 4, cites the idea of *dynamical equilibrium*. She refers to a system characterized by a balance of elements that remain more or less the same but recognizes that something always changes and does not freeze ("more or less the parts are those, but it is a continuous change, a continuous movement").

The Priorities for the School of the Future According to the Students

To understand and describe how students imagined the future of the school, we analyzed the final presentations given by groups 4 and 7. We will present the results of the analysis developing a narrative that goes across the macro-themes identified, to give back a picture of the main problems that the students see in the school nowadays, the features of their ideal school, and the kind of transformation that needs to take place.

The Problem of Students' Anxiety About Their School Performance

The traditional methods of knowledge assessment and evaluation are perceived by both groups as a considerable source of stress for the students. In particular, the final exam of high school (in Italy, the "maturità"), is a sort of threat for the students during the whole school path.

However, in a perspective of maintaining a certain balance within the system (as discussed above), they do not propose abolition of texts, exams, and grades. Indeed, to a certain extent, forms of evaluation are believed to be a fruitful resource for the students and helpful for learning. To keep the motivation but reduce the stress connected to the marks, group 4 suggests, for the tests, to move from an evaluation in a 0–10 rank to a ranking with letters from A to F. They do not explain the advantages of using the letters as a ranking system, but we can suppose that there is in the students a certain pop-cultural fascination for what happens in the United States, as an example of innovation. More ideas are proposed by the students of group 7 who reflects on the possibility of a better organization of the workload to avoid too many tests in a too short period of time. The teachers appear as protagonists of the change of school from the very first sentences of the presentation. Later on, they will illustrate how their role is essential for the transformation they hope for. To reduce the anxiety for the final examination, they ask for an evaluation system that takes more into account the achievements throughout the whole school path, without basing only on the performance in the exam.

The Role of Technology in Science Innovation

The technological dimension has a relevant role in the innovation of the school system that the students advocate. Its use is foreseen to contrast the traditional teaching methods that the students consider "boring and not very interacting". They say that technological devices are already part of some teaching activities, and the process has recently accelerated because of the massive implementation of distance learning imposed by the pandemic. However, always in a logic of balance and gradual transformation, the students of both groups believe that technological innovation must not replace traditional learning tools. In particular, according to group 7, keeping textbooks made of paper is necessary in order to "organize the study". We can read, behind this apparently simple sentence, an implicit idea of the students: if new methods (represented by the "technology") can innovate school making it more entertaining, more pleasant and less boring for students, it's from traditional methods (represented by the "paper" and the "books") that comes a precise and solid form of organization of knowledge and this organization is what allows the students to orient themselves in all the pieces of information. Coherently with this interpretation, we also have group 4 which imagines use of technology that should allow closer interaction between teachers and students. This shows how technology itself needs to support the students in their learning processes but cannot replace the confront with the teachers as the repositories of organized, authentic, and validated knowledge. On the opposite, the platform that the students imagine is designed to facilitate the process of teachers' supervision of the students. Group 4 also reflects on the health issues related to the widespread use of technological devices, imagining that those tools will be used only starting from middle school.

The Re-thinking of School Knowledge

In front of what group 4 calls "the classical notional and frontal teaching method", the students do not only refer to technology as the solution to their problems. They imagine a variety of changes that need to be done to make learning, on one side, more pleasant for students and, on the other, more relevant for their personal future and careers.

One problem that the students experience is related to the frenetic rhythms of the classes, with a too intense concentration of information in a too short period of time. For group 4, knowledge requires time to be assimilated and understood, while the current organization of the school timetable and the curricula implies dense lessons in which a lot of information is given. They not only think about a change of the rhythms of the classes but imagine also that the type of knowledge provided should be rethought. The "notional" lessons are counterposed with the "concrete" character of knowledge they would like to learn. They believe that school should teach more about the applicative issues embedded in the disciplines to prepare the students for the world outside and after school. The students imagine a variety of activities with which the school curriculum should be enriched: courses in the afternoon, school trips, internships, university, and career orientation activities (they cite, for example, the PCTO activities, "Percorsi per le Competenze Trasversali e l'Orientamento" that are programs in Italy aimed to develop transversal competences and prepare for the university or professional choices after high school). All these are experiences that already exist in the school and that are present in the official curricula. The emphasis that the students give on them reveals their appreciation of engaging in activities that allow to widen the knowledge learned in the classroom, find application contexts for that knowledge and understand their attitudes.

Another difference between the school they experience and that they would like is related to peer instruction. The suggestion of introducing peer instruction in all schools can be interpreted as another dimension of change in the forms of how knowledge is constructed. According to students' ideas, the teachers will not be the only repositories of knowledge but there can be some spaces during the school routine in which some form of knowledge is developed thanks to the interaction with mates. This point will be furtherly discussed in the following paragraph.

The Dream of School as a Place for Relationships

An element that characterizes students' ideal school is the quality of relationships between the protagonists that live in the school in the first place: students and teachers. The ideal school dreamt by the students is centered around relationships. And there is more than that: we can read a sort of positive feedback that makes the school environment a carrier and support of relationships between students and between professors and students, but the quality of these relationships makes school learning more effective, and the school environment results enriched. These relationships are exploited in different activities. In the previous paragraph, we have already mentioned peer instruction, but there are other kinds of moments in which students can for example meet to study in groups or with a professor. In these activities in which the teacher participates in the moments of study, the students can "re-evaluate" the "image of the teacher", establishing a "bond" with them.

The Priority of School at the Center of the Youngsters' Routine

With the second and third macro-themes, we have already introduced some elements regarding the different organization of time imagined by Group 4. For example, they mentioned the idea of the fair amount of time needed to learn and appropriate disciplinary concepts, or the necessity of spending extra time at school in the afternoon to strengthen relationships with mates and teachers. They also mention that more time spent at school would reduce the time spent by students for their individual study. From the students' words, emerges the desire of the students to have back the time that in their routine they spend at home and devote to self-study. Later in the presentation, they sketch out a normal day in their ideal future: for these students, the school is the main place around which the youngsters' routine should be centered, with 8 hours spent there every day. School seems to be so important that includes in it almost every aspect of the students' life: the access to institutionalized knowledge (with the most traditional classes in the morning), the experience of fields of application of what they have learned (with the laboratory activities, meetings with experts or trips), the cultivation of meaningful relationships with teachers and mates (during the group study or lunchtime), the practice of recreational activities like sports. With the imagination of the future ideal routine, the students display the need for an almost fully institutionalized routine, where most dimensions of life are covered by the school program. However, it is thanks to this dense timetable that the school can contribute to free the time that the students have beyond school, like the "time for themselves" that the students claim to need as well as the relationships with friends and family.

The Role of Students and Teachers' Agency in the Process of Change

One of the most frequent macro-themes identified in groups' presentations was the importance of students' and teachers' agency in the process of realization of the desirable future. Their agency covers three main dimensions: the *public* (establishing a relationship with the institutions), the *professional* (involving the relationship with colleagues), and the *personal* dimension (carried out in the personal routine).

The public dimension is identified when the students talk about collective protests, marches, and petitions in which students and teachers take part or when they refer to awareness campaigns on social media or in the schools. All these forms of actions relate to the public dimension since they have the explicit goal to raise the government's attention about the situation of the school (petitions, marches, and protests) or to involve others in the movement (campaigns on media):

> *Then after the pandemic people realized how badly the school was managed due to the uncertain indications that always arrived late and subsequently thanks to the demonstrations and requests of the students their ideas were taken into consideration by adults. These events have made possible a greater dialogue between educational institutions and students. The attention from the government towards the school has also increased in fact financial investments have been made. [. . .] We have identified two main actions that we can do to improve the situation. The first is to manifest, both in the strict sense precisely with organized events about we have been talking a lot lately, and also a manifestation in a broader sense, in the sense of manifesting one's thoughts personally or even at a class level, to the school, so encouraging dialogue between students and teachers and the school organization. (Group 7)*
>
> *Because of this, it is necessary a sort of activism on the part of students and teachers who can therefore make petitions or even movements on social media to the mass media. In this way, many more people would come into contact with this thought and maybe it would also spread the fastest way since we can exploit a tool that is still very prevalent today in life, especially of young people. [. . .] Finally, an effort is needed on the part of everyone, especially the students. In fact, it is the students themselves who mobilize themselves to bring about a change in Italian education. Because of this, it is necessary to awaken in a certain sense the students from the passivity that lies in these days, in this period. More than passivity I would say indifference towards the school since now it is almost like torture many times. To this extent, we need movements that can reach everyone so that they realize that the school can change and they can do something to help. (Group 4)*

We can recognize that with the idea of agency in the public dimension comes the recognition of the roles of institutions with which, as said by group 7, a dialogue can be established. Moreover, the students realize that acting on a public dimension is not limited to the dialogue with the higher-level institutions (e.g., the government) but also involves mid-level actions of awareness-raising at the class or school levels.

If the public activism involves students and teachers who take part together in the transformation of the school, the second dimension of agency, the professional one, mainly regards the teachers. Especially group 4 focuses on the fact that, to trigger the desired transformation, the teachers need to take part in courses of professional development where they work together with their colleagues to figure out ways to innovate their teaching and, hence, school.

> *Furthermore, it is also difficult to find teachers willing to try new teaching methods. In this case, projects or courses could be set up for the teachers themselves so that they have the opportunity to discuss with each other to devise new teaching methods and perhaps even discuss them with the students in order to have their approval. (Group 4)*

The last dimension relates to the personal agency of students that covers the context in which they act without interacting with institutions and peers but in their personal lives and routines. Group 7, for example, focuses on the hard work of students in order to "get the work done" personally.

> *And the final thing and perhaps not the most important is the management by the students in their autonomy of the tasks and projects they have to carry out because it can manifest as long as you want, you can have a perfect school system but, in any case, you have to work and you have to get the work done to get results. (Group 7)*

The Hope for Pandemic as an Activator of Transformation

In the presentations, both groups referred to the role of the pandemic (that in their scenario of 2040 occurred twentyish years later) in the process of transformation of the school. From one side, the pandemic raised the issue of the importance of technology, which we already addressed with the analysis of the first macro-theme. But the importance of the pandemic was not only that of suggesting a way of change like the use of more digital devices but was also a trigger of transformation. Indeed, as group 7 points out:

> *Then after the pandemic, people realized how badly the school was managed due to the uncertain indications that always arrived late, and subsequently thanks to the demonstrations and requests of the students their ideas were taken into consideration by adults. These events have made possible a greater dialogue between educational institutions and students. The attention from the government towards the school has also increased in fact financial investments have been made. Finally, thanks to these investments there has been an innovation in the school system, schools, and equipment. All the things we said before have changed. (Group 7)*

Again, the importance of students' agency is underlined. Indeed, the group recognizes retrospectively the role of the protests that occurred during the pandemic in starting a durable change. The students' actions made a difference because the government decided to make more financial investments to improve the school system. In some sense, for both groups, the pandemic created the conditions for the realization of the desirable future.

Overview

After having presented the meaning of the different macro-themes, in **Figures 3**, **4**, we report, with two different visualizations, the distribution of the macro-themes in the two groups' presentations. In both figures, on the left, there are the

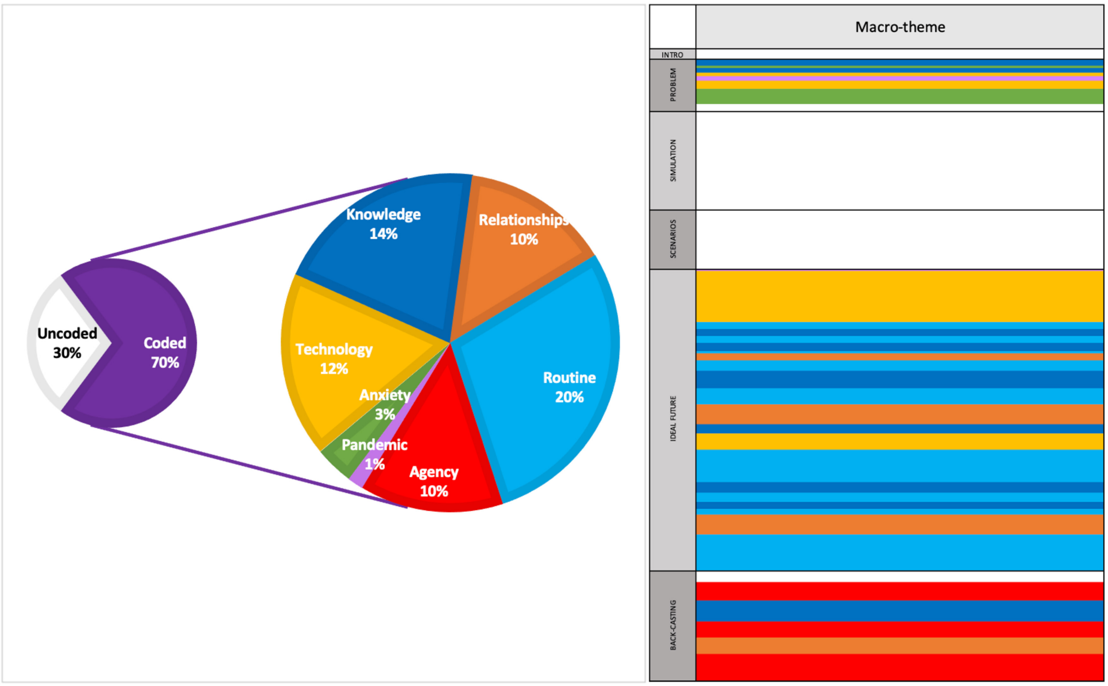

FIGURE 3 | Distribution of the macro-themes in Group 4's presentation.

pie charts for the frequency in the transcripts of the seven macro-themes. The pie charts contain a first graphic with the percentage of the coded and uncoded transcript (coding coverage) and then it is reported the details of the percentage distribution of the seven categories on the coded portion of the transcript. All the numerical values have been calculated using the number of words in each excerpt. The second visualization, on the right of **Figures 3**, **4**, consists in the miniatures of the transcripts of two presentations (the readable versions are reported in Barelli, 2022) with the distribution of the macro-themes. In this case, the height of rows is proportional to the number of words in the specific excerpt of the transcript.

The difference between the two kinds of visualization is that in the second we have the chronological articulation of the occurrence of the macro-themes across the development of the presentation. In particular, we have divided both presentations into six phases that corresponded to the tasks in which the activity was articulated: introduction, statement of the problem, introduction of the simulation, explications of the scenarios obtained with the simulation, presentation of the ideal future, and back-casting.

Even if the two presentations are very different for their extension (more than 2,300 words for group 4 and less than 1,000 for group 7), we can draw some common considerations about both.

A first observation is methodological and can be done by looking at the portions of the coded and uncoded transcripts. In both cases, we notice that there are significant parts of the transcript that could not be coded using the seven macro-themes. This percentage is 30% in group 4 and grows up to 42% in group 7. Apparently, this would mean that from the bottom-up phase of coding to the identification of the macro-themes, many excerpts of text could not be captured by the macro-themes. However, if we look at the right part of **Figures 3**, **4**, we can notice in which parts of the presentation there are the uncoded parts. For both groups, most uncoded parts are in three phases: the short introduction to the presentation, the phase of description of the simulation, and that regarding the scenarios obtained using the simulation. This is all but unexpected for us. The reason behind the absence of coding in the introduction is rather trivial: here, the students briefly summarized the content of the presentation, the name of their group, and outlined the general structure of the presentation, without entering the content of their investigation. We can easily explain the absence of macro-themes in the other two phases too: those parts of the presentation were interpreted by the students as the most technical ones, in which they had to "play the role" of scientists and experts of simulations, presenting the reasons for the choice of the model and showing its functioning. If we exclude these three sections by the count of the uncoded transcript, we notice that remain only a few excerpts. Both for Group 4 and 7, they are positioned at the joints between the sections and are sentences that connect one part of the discourse to the following.

A further comment is needed on the distributions of macro-themes related to agency and pandemic.

For both groups, we can notice that in the back-casting phase are concentrated the excerpts related to agency (in red, following the color coding). To explain this, we recall that in this part of the activity, and consequently in this part of the presentation, the students had to think about the possible events that could have

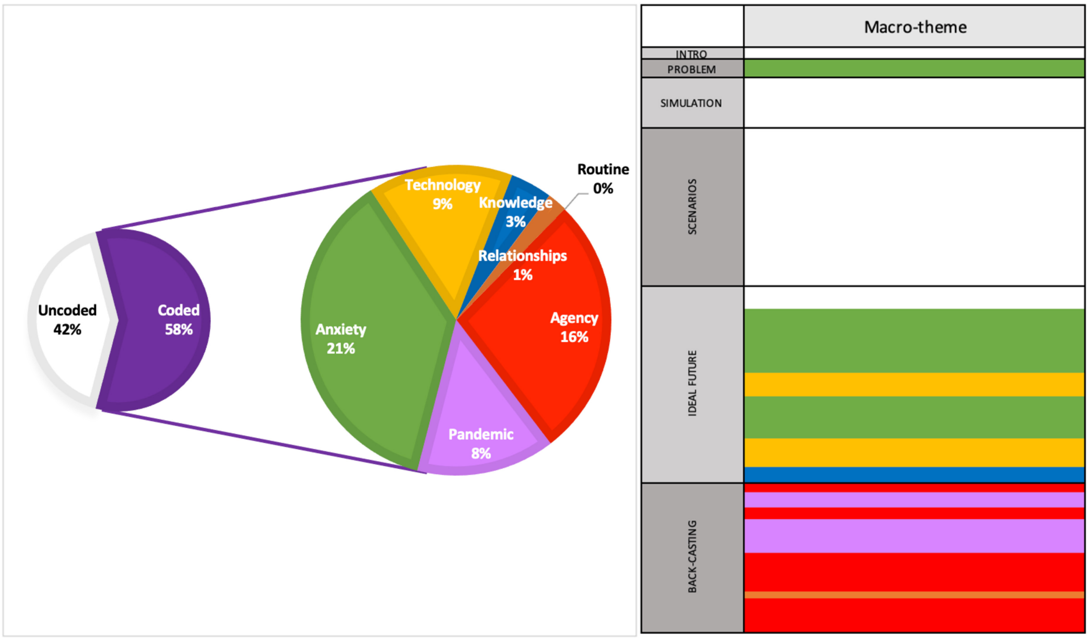

FIGURE 4 | Distribution of the macro-themes in Group 7's presentation.

led to the desirable future in 2040. Of the range of possible events and actions, the students emphasize the role of their own agency, as students, in changing the system.

We have already discussed how the students imagined the role had by pandemic on their possible and desirable futures and talked about this in the presentation. However, the two groups mentioned the pandemic in different parts of the presentation. Group 4 dedicate only a very small part of the presentation (around 1%) to this issue. In particular, they used the pandemic as the starting point to introduce the problem of their interest (the resistance of the school to innovate, also technologically, its methods) and then they mention it at the beginning of the description of their ideal future that is partially inspired to the use of technologies experienced in the on-going pandemic. For group 7, the reference to the pandemic is much more frequent (around 8% of the total presentation) and concentrated in the back-casting phase. This indicates that the students recognized the pandemic as a historical moment in which specific actions, such as public protests and petitions, have been possible: for them, the pandemic (and what happened during it, especially in terms of social awareness and agency) is part of the sequence of essential actions that can realize the desirable future.

The macro-themes related to agency and pandemic are the most connected with the issues on which RQ2 is focused. However, we want to conclude this section commenting other two macro-themes that appear with different frequencies in the two presentations, allowing to highlight the specificities of the groups of students in terms of the important changes to be made to reach the desirable school.

The biggest difference that can be noted comparing **Figures 3**, **4** is the appearance, in the figure related to Group 4, of the macro-theme of routine that is totally absent in that related to Group 7. This macro-theme covers around 20% of the whole presentation of group 4. This can be partially explained with the choice of Group 4 about how to structure the presentation. Indeed, the second half of the section about the explication of the ideal future was dedicated by the students to present their daily routine in the preferred 2040. This made explicitly recognizable the macro-category related to routine. However, the high frequency of the macro-category does not only depend on the choice of presentation because even in the first part of the section the category was highly present. This suggests that for Group 4 the revision of the times structure of school was of fundamental importance.

Another category whose frequency differs a lot between the two groups is that related to the issue of students' anxiety toward school performance. If in Group 4 this macro-theme covers 3% of the presentation, this percentage grows up to 21% in Group 7. Observing the position in the presentation of the macro-theme, we notice that for Group 4 it is part of the introduction to the problem, alongside many other themes related to the role of pandemic, of school knowledge, and of technologies. In the following sections of the presentation, the issue is not touched again because they mainly focus on addressing the issue of technological innovation as a response to the problem of teaching methods. On the opposite, for Group 7 this macro-theme is more organically present in the presentation. The only problem they mention is the students' anxiety toward school and it is not surprising that, in describing their ideal future, this dimension occupies large parts of the section.

DISCUSSION

The richness of students' presentations at the end of the future-oriented activity is suited to many different highlights. We will discuss mainly two points that relate to the main themes of the special issue of which this paper is part.

Analyzing the students' presentations, it emerged very clearly the importance that the groups gave to the idea of equilibrium in the construction of the different scenarios. This was surprising because, if for the futures studies the concept of equilibrium is at the basis of the formulation of authentic scenarios (Greeuw et al., 2000; Kosow and Gaßner, 2008), this is difficult to be identified by novices reasoning on future-oriented issues. Indeed, in previous experiences within the ISEE project, the desirable scenarios imagined by students were always very extreme (Barelli, 2017). Indeed, the imagination of a desirable scenario triggered attitudes of detachment from reality that resulted in fictional, idealized futures that were static pictures of a future without any possible conflicts between interests or people. On the opposite, it is intrinsic to the notion of future scenario the description of a state of future equilibrium of the system. The equilibrium state, to be realistic, must foresee differences among interests and stakeholders, and circular interactions between agents in the systems. In previous studies, students' desirable scenarios gave back, instead, a picture of, metaphorically speaking, "thermodynamic equilibrium" where conflicts, interactions, and differences among the stakeholders were minimized (Barelli, 2017).

Even in an experience carried out with university students (Barelli and Levrini, 2021), the type of scenarios obtained lacked this aspect of equilibrium and the students felt they were not reliable since they exaggerated specific aspects of a problem. On the opposite, in the course with high-school students, we have observed that an accurate work on simulations (carried out during lessons 3 and 4 with the analysis of three simulations of reference and then with the establishment of correspondences with real-life issues) made it very natural for students to imagine scenarios of equilibrium, even if this concept had not been introduced explicitly. In the implementation with university students (that covered 6 hours of teaching instead of the 18 hours of the course with high-school students), the participants had been only introduced to the features of equation- and agent-based simulations, then they were left rather free of exploring NetLogo models in groups during the future-oriented activity. In particular, the activities of interactive analysis of selected NetLogo simulations and of analogies' development were not carried out. Hence, we can hypothesize that an in-depth analysis of the models offered by the instructor followed by hands-on experiments in the virtual laboratory of simulations allowed the students to elaborate their desirable scenarios either as interpolations between two extreme scenarios or as representations of the equilibrium behaviors displayed by the simulations in specific conditions. The resulting scenarios of dynamical equilibrium were authentically *sustainable*. Indeed, they included tensions between the needs of the present and those future generations, between traditions and innovations, and between practical requirements and desires (WCED - World Commission on Environment and Development, 1987; Murphy, 2012). Moreover, envisioning a complexity of tensions, they seem to accept the irreconcilability of the conflict (Weber, 1958) which also makes the scenarios reliable: for those groups that eliminated every form of conflict from their future, it appeared meaningless because utopian and impossible to be realized.

The second point that deserves discussion regards the emphasis given by the students to their own agency in the process of transformation of the school toward the desirable scenarios. The structure of the future-oriented activity was explicitly designed to make students reflect on their role as agents of change, able to impact the present in the light of their desires for the future. For example, in the back-casting phase, they were asked to identify the actions, decisions, or policies that occurred in the imagined timeline. In particular, they had to make explicit their role as agents in the path of changes from the present to the future they foresaw, as professionals, members of society, and individuals in general. Not only the future-oriented activity included an explicit request for students to reflect on agency, but also the whole course with its focus on the agent-based simulations underlined the importance of the individuals and their actions in the interaction with others to produce certain evolutions of the system. In this sense, the way toward agency had been paved throughout the module, both from the conceptual, the epistemological, and the societal perspectives.

However, the results achieved by the participants went over the expectations. In the future stories elaborated by the students, we clearly identified three dimensions of agency: the *public* (establishing a relationship with the institutions), the *professional* (involving the relationship with colleagues), and the *personal* dimension (carried out in the individual routine). These can be conceptually associated with the three "spheres of transformation" (O'Brien and Sygna, 2013; O'Brien, 2018) that are the practical, the political, and the personal. In this model, the practical sphere is usually associated with the idea of transformation throughout expertise and in our case is connected to the professional dimension of agency. Then, the political sphere can be linked to the public agency, since in both cases an impact on institutions and societal structures is implied. Finally, we have the personal sphere which is the most blurred of the three. Indeed, following O'Brien, this is the sphere "where the transformation of individual and collective beliefs, values and worldviews occur" (O'Brien and Sygna, 2013, p.6). In our case, students' words to describe this change cannot be explicitly associated with values and worldviews, because they are more linked to an aspect of routine and to a very local agency made of concrete actions. In some sense, the personal dimension of agency could be interpreted as another shade of the practical sphere of transformation.

CONCLUSION

In this paper we have shown how the future-oriented activity was for some students an opportunity to reason about the school they desire. During the presentations of their work, the students pointed out well-known problems that the current organization of the school is facing. Thematic analysis has been carried out to identify the main macro-themes which emerged from the presentations and the interviews. From the analysis of the groups' presentations, we found that the students suffer a great problem of anxiety about their school performance and imagine that this can be mitigated in the school in the future. They see the importance of the role of technology in school innovation but also that no innovation is possible if school knowledge is not re-thought of its times and forms. The students dream about a school as a place for relationships and that can become at the center of the youngsters' routine. In particular, we have pointed out that the students deeply recognize the power of their own agency and that of their teachers in the process of school transformation, and hope that the tragedy of a pandemic can be transformed into an opportunity to trigger change.

However, the school that the students imagine as their desirable one is not idealized as a utopia: like most of the other groups working on different topics, the participants were able to see a scenario—even the preferred one—as a complex interaction of many stakeholders and as a tension between opposite interests that the different agents have regarding a topic. Experimenting with the NetLogo simulation, the participants observed both divergence scenarios, in which for example a class of agents totally defeated the other, and equilibrium scenarios where a dynamical balance assured the sustainability of the system and its credibility.

The students' enthusiasm in reasoning about the school of the future demonstrated in the implementation described in this paper led us to design further activities in which the students were explicitly required to select, as a future-oriented issue, a problem related to the current school system and to analyze it with a simulation. This activity has been carried out both with prospective teachers and with high-school students and the results appear promising.

In the incipit of the paper, we stated how the history of computational simulations began in war times and dramatically contributed to catastrophic events of the past. It has been comforting for us, especially in these days when the world is shaken again by the fear of war, to see how, through future-oriented science education, these computational objects can become tools to dream about the future, not in a naïve way but in a sustainable—hence actionable—perspective.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: http://amsdottorato.unibo.it/10146/ (Barelli, 2022).

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Alma Mater Studiorum – University of Bologna. All data discussed in this paper were collected and analyzed in compliance with the European Union's Regulation for Data Protection (GDPR) as made explicit in the Ethics Requirements of the FEDORA Project in which this research is framed. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

EB conceived and designed the study, collected the data, performed the analysis, and wrote the manuscript.

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