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Using a knowledge structure perspective to improve in-service teachers' content knowledge about active galaxies

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The aim of this research study was to explore learning, i.e., changes in the knowledge structures of three in-service science teachers for the subject of active galaxies, through group activity conducted as part of a teacher training program. Qualitative methods were used in this study consisting of creating visual representations of the teachers' knowledge structures by analyzing texts, drawings, and data obtained through observations of and interviews with the teachers. The results show that new information acquired through conversations was incorporated into the teachers' preexisting knowledge structures through elaboration and organization. In the case of a teacher with a cognitive conflict, acceptance of the new information depended on the teacher's level of satisfaction with the explanations given. The main influence factor for the modification of knowledge structures was the teachers' orientation to science teaching. These findings suggest that in-service teacher training based on group activities can effectively enhance teachers' confidence in content knowledge (CK) of recent updates in scientific research. However, some format modifications are needed to guarantee efficient learning, such as the addition of a CK representation stage and discussion items based on the preactivity knowledge structure selected through expert review.

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I. INTRODUCTION

Astronomy has the potential to ignite the interest of young students in science. However, astronomy is often considered a difficult subject to teach or learn because of the perception that a strong foundation in mathematics and physics is required. Astronomy deals with vast spatial and temporal scales [1] and encompasses abstract concepts that are not tangible or operational, which presents challenges to teaching and learning [2–4]. A shift in thinking is required to interpret observational phenomena that are often counterintuitive, which makes astronomy education even more challenging [5–9]. Modeling, involving the processes of building, applying, and evaluating appropriate scientific models to explain phenomena, plays an important role in science learning [10–12]. A good understanding of the modeling approach and its applications is necessary to effectively design astronomy lessons [13]. Furthermore, it is important to design astronomy lessons considering students of different levels. These considerations highlight the importance of educators' pedagogical content knowledge (PCK) for providing a high-quality astronomy education [14,15].

As in all other scientific fields, the quantity of scientific knowledge in astronomy is continuously growing through new research discoveries. This new information is introduced to teachers and students through various channels. However, in-service teachers who instruct subjects related to astronomy often lack self-efficacy regarding their content knowledge (CK) about new research results. Studies suggest that CK and PCK can influence each other [16]. The development of both CK and PCK enhances teachers' ability to design effective lesson plans, which, in turn, can positively affect students learning [17–19]. Therefore, it is important to put effort into improving teachers' CK of newly introduced scientific results. One possible solution is to design an in-service teacher training program that is

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easily accessible and sustainable, without unnecessary complexity.

There are various types of in-service teacher training programs, including regular courses for higher degrees, expert lectures, workshops for moderate-sized groups, supervision by senior teachers, and self-study of the professional literature [20]. Among these programs, moderate-sized group workshops are the most sustainable method, particularly in Korea where the local Ministry of Education encourages community activities for teachers. Teachers with similar backgrounds voluntarily form communities and engage in peer teaching quite frequently. However, there may not always be an expert in a specific subject matter (in terms of CK) in such a community. To maximize the positive influence of teacher-teacher interactions in community-based training, it is important to explore how teachers learn through interactions with their peers to gain insight into the design, improvement, and assessment of a program.

The aim of this study was to explore how teachers learn through nonguided group activities. Group activity is a popularly used active-learning practice in science education, thought to be effective in motivational, affective, and cognitive aspects [21]. Discussions that occurred during the group activities encouraged cognitive conflicts to arise, leading to an enriched understanding of the subject matter. From this point of view, we designed a teacher training program with a form of group activity to investigate the teachers learning through the program. In this work, “learning” is defined as the process of acquiring new knowledge through experience. New information is best understood when it is connected to and builds upon an existing framework, which was defined in this study as a “knowledge structure” that enables learners to gain a deeper and more meaningful understanding of a subject [22]. We used visual representations of knowledge structures to explore how learning occurs. Knowledge structures contain interconnected concepts and links that show how new information is integrated and stored in relation to existing knowledge. Our aim was to compare the learning outcomes of individuals who participated in a group activity to investigate the impact of different factors on learning. We expected that this study would enable us to identify areas for improvement and develop guidelines for future teacher training programs. The following questions were investigated in this study.

RQ1. How do teachers learn?

RQ2. What factors influence teacher learning?

RQ3. What should be considered when designing teacher training programs in the form of nonguided group activity lessons?

A. Active galaxy, nucleus, and unification model

The subject of the in-service teacher training program discussed in this paper is active galaxies. This term encompasses a variety of unusual galaxies, such as Seyfert galaxies, quasars, and radio galaxies [23]. This topic was selected because there is relatively recent information on this subject that many in-service teachers may not have had a chance to acquire through regular course lectures before becoming teachers. Thus, it is necessary to establish related CK for in-service teachers. Additionally, it is easy to demonstrate how new information is integrated into the existing knowledge structure.

An active galaxy is a galaxy that emits strong radiation across most wavelengths. Typically, galaxies (also called normal galaxies) exhibit a spectral energy distribution with a peak at optical wavelengths that is dominated by stellar radiation. The spectral energy distribution sometimes also contains a peak in the infrared caused by blackbody emission from heated dust. However, active galaxies frequently exhibit flux excess in x-ray, ultraviolet, far-infrared, and radio wavelengths compared to normal galaxies, because the emission of an active galaxy is dominated by the centrally located supermassive black hole. The central nucleus of an active galaxy is called an active galactic nucleus (hereafter AGN, [24,25]).

Figure 1 is a schematic diagram of the structural model of an AGN [25], which is suggested to explain the observed variety of different classes of active galaxies. A hot ($\sim 10^5$ K) accretion disk is located at the center of an active galaxy over a scale of less than 0.1 parsec around a supermassive black hole with a mass of over millions of solar masses. A jet is frequently ejected perpendicular to the disk. Fast-moving, hot gas clouds are populated at the parsec scale and produce emission lines of which line widths are large. This region is called the broad line region (BLR). Beyond the BLR, where the temperature drops below the sublimation temperature, a torus-shaped structure composed of dusty particles is expected to block the sightline. The ionized gases over a considerably larger

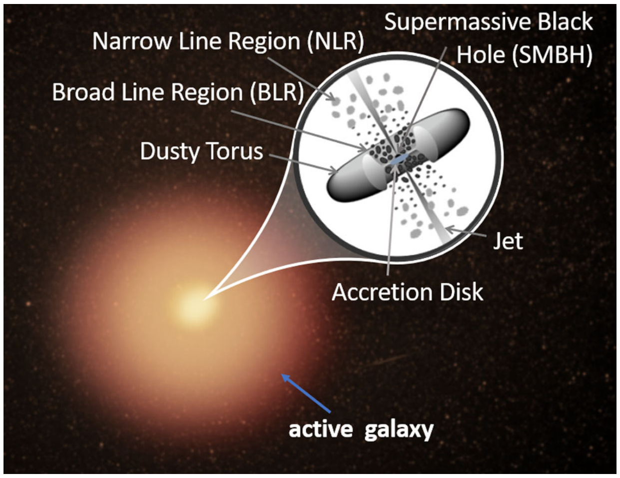


FIG. 1. Schematic diagram showing an active galactic nucleus centered on an active galaxy (reconstructed from Ref. [25]).

cone-shaped area produce emission lines moving at lower speeds and thus, with narrow line widths (corresponding to the narrow line region, NLR).

Within this scientific model, known as the AGN unification model [25], the main factor that determines whether an object will have the observational characteristics of type-1 and type-2 Seyferts, quasars, radio galaxies, and blazars is the viewing angle between an observer's sightline and the disk edge. Considering that the typical size of a galaxy is a few to tens of kiloparsec, the central AGN is very small compared to the whole galaxy. However, in active galaxies, emissions from the center dominate the emissions from the whole galaxy, making the center exceptionally bright.

B. Active galaxies in the curricular context

In preparation of the teacher training program, it is worthwhile to explore how the subject is implemented in the science curriculum of secondary schools. As the topic of active galaxies is a highly specific subject, we investigated the more general term, "galaxy," within the curricular context.

In Korea, "science" is a compulsory subject for students from the 3rd to 9th grade, whereas "integrated science" is mandatory for students in the 10th grade, the first year of high school. Students can subsequently choose to take more intensive courses, such as physics and earth science. Although some subject matter related to astronomy, such as gravity and the application of optics to telescopes, is included in physics courses, astronomy is mostly covered in earth science. Curriculum contents and learning standards are revised occasionally, and the 2015 Revised Curriculum (which followed the 2009 Revised Curriculum) was used in schools at the time of this study.

The 2009 Revised Curriculum involved providing key ideas about our galaxy in the 8th-grade science subject, followed by an explanation of cosmic expansion using a balloon experiment as an analogy. The concept of galaxies was introduced to explain the expansion of the Universe, along with the proposition that the distance between galaxies increases because the Universe is expanding. However, there was no further description of the observational characteristics of galaxies other than that galaxies are stellar systems similar to our Milky Way galaxy. Overall cosmic history, from the big bang and element synthesis to the formation of stars and the solar system, was included in the integrated science subject for the 10th grade. The content of the compulsory science subject in the 2015 Revised Curriculum is more or less similar to that of the 2009 Revised Curriculum and is taught in the 9th grade instead of the 8th grade. Storytelling about cosmic history is removed from the integrated science subject, except for the very first part of big bang nucleosynthesis that produced hydrogen and helium.

The characteristics of galaxies were only included in the elective subjects. The 2009 Revised Curriculum introduced Hubble's morphological classification system [26] and "peculiar galaxies," including quasars, radio galaxies, Seyfert galaxies, and merging galaxies, in the 12th grade. In the 2015 Revised Curriculum, the same ideas related to Hubble's classification system and the variety of galaxies are taught at the 11th-grade level.

In addition to the frequent shifting of subject matter across grade levels, the current composition of content on galaxy classification and variety of galaxies (including active galaxies) can create a conflict between morphological classification and spectral classification of galaxies, without clear differentiation between the two. The detailed physical radiation mechanisms that produce x-ray and radio emissions from central AGN are not included in the secondary school curriculum. As a result, both students and teachers find it challenging to accept the idea that morphologies of active and normal galaxies can be similar in observed images.

What would be an appropriate way to introduce the various types of galaxies and what would constitute the key idea or essential astronomy literacy for students? One possible answer can be found in "Big ideas in astronomy" [27], maintained by the IAU-OAE (International Astronomical Union Office of Astronomy for Education), which covers 11 big ideas in astronomy, including subideas related to galaxies and galaxy evolution. These ideas include the following concepts: (i) "A galaxy is a large system of stars, dust, and gas." (ii) "Galaxy formation is an evolutionary process." (iii) "There are three main types of galaxies: spiral, elliptical, and irregular." (iv) "Most galaxies have a supermassive black hole at their center." In this publication, active galaxies are not presented separately from normal galaxies, and a rather robust proposition, "most galaxies have a supermassive black hole," is adopted. This proposition is in line with the scientific interpretation that active galaxies may represent a temporal stage in galaxy evolution at which the contribution from supermassive black holes to the total emission is most significant.

Although the curriculum and textbooks provide guidelines, it is ultimately the responsibility of teachers to structure course content. Our training program on active galaxies is designed with two goals in mind: to provide guidance to teachers on scientific ideas and concepts and to provide opportunities for teachers to learn through interactions. Achievement of these goals is assessed based on the amount of learning during the activity.

II. METHOD

A. Participants

The participants of this study were three science teachers currently working in secondary schools in Korea. These teachers were selected by criterion sampling [28], based on (i) prior experience of teaching topics related to galaxies and the Universe in middle or high school, (ii) availability to participate in group activities on site, and (iii) initiative for interaction with others during group activities.

TABLE I. List of participants' background information.

Participant	Teacher A	Teacher B	Teacher C
Teaching years	4	11	12
Current teaching subject	Science (middle school)	Science (middle school)	Earth science (high school)
Previously taught topics	Our galaxy (9th grade) Expanding Universe (9th grade)	Our galaxy (8th grade), Cosmic expansion (8th grade)[a] Cosmic history (10th grade)	Various galaxies (11th grade), Hubble-Lemaitre law (11th grade), Big bang cosmology (11th grade)
Major	Earth science education	Earth science education	Earth science education

[a] Based on the 2009 revised curriculum. Teacher A and C's teaching experience is based on the 2015 revised curriculum.

The teachers were invited to participate in a newly designed teacher training program on galaxies and the Universe. The participants joined the program with the aims of acquiring new knowledge (Teacher B), gaining new perspectives and assessing existing understanding (Teacher A), and increasing confidence in teaching the subject to students (Teacher C). At the time of participation, Teachers A and B were working in middle schools, whereas Teacher C was affiliated with a high school. Teacher A had never taught in a high school. Teacher B had taught a 10th-grade integrated science course in a high school several years ago, as well as 8th-grade science in middle school, before moving to current school. Teacher C had spent most of teaching career in high school. Table I presents the background information of the participants.

B. Research design

A one-group pretest-post-test research design was used in this study. The participants went through a teacher training program, and their knowledge structures before and after the program were investigated. The teacher training program consisted of four classes conducted over two sessions. The first and second classes were held in the morning and afternoon of the same day, and the third and fourth classes were held one week later. The pretest was sent to participants via email one week before the first class so that they could submit their answers beforehand. Participants were asked to complete the pretest at least two days before the class. The post-test was also sent to participants via email after the last (i.e., fourth) class took place. After the post-test answers were received, one-on-one in-person interviews with the participants were carried out.

C. Program design

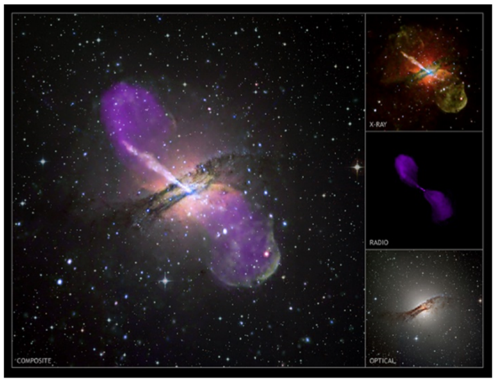
The teacher training program on "Galaxies and the Universe" was developed using an Analysis, Design, Development, Implementation, and Evaluation framework [29]. The main topics (active galaxies and cosmological models) were selected based on an online survey sent to 19 science teachers who were members of the earth science teachers' community in the district of the local Ministry of Education. A pilot study was conducted before conducting the main study to evaluate the developed training program. The training program was revised based on feedback from the pilot study participants.

The first half of the four classes focused on the morphological classification of galaxies and active galaxies, and the second half focused on the expansion of the Universe. In the first class, the participants developed a classification system for galaxy morphology in radio wavelengths, with the key idea being that galaxies appear different at radio and optical wavelengths. In the second class, the participants built a three-dimensional (3D) AGN model using everyday materials to understand the relative scale of the nucleus to the galaxy. In the third class, the participants used a photocopier and transparencies to make a demonstration of the expanding Universe. Finally, in the fourth class, the participants produced a plot of the redshift versus the luminosity distance using published Type Ia supernovae data, and compared the observations to different cosmological models. In this paper, we only present results from the first and second classes.

The two main components of the developed teacher training program were "modeling" and "group activity." Modeling is the process of constructing and using scientific models. It is widely accepted that modeling is useful in science education for enabling students to understand how science is done and learn scientific concepts [10–12]. Various types of models are frequently used in science education. The 3D AGN model constructed in the second class was a scale model [30]. A concrete scale model is designed to be considerably smaller but geometrically similar to the respective real object. However, for many astronomical objects and phenomena, relative size and distance are difficult to scale linearly because of the large difference in the sizes of the model and object. Thus, many artists' impressions of astronomical concepts include a "not-to-scale" comment. The participants were allowed to build a model freely with a consultation to references, to investigate how they establish connections between an analogous model and a real astronomical object.

In the developed teacher training program, participants were required to work together to create an output product during each class. Rich conversations among the participants were thus facilitated. Participants were encouraged to actively communicate with each other and consult reference materials, such as books and online resources while

Preactivity questions



- **Explain why this object looks different in different wavelengths.**
- **Classify this object based on Hubble's tuning fork. Provide your reasoning.**
- **Draw spatial distribution of stars and gas associated with this object. Explain your reasoning.**

Postactivity questions

- **Explain how your handmade model is related to a real active galaxy. If your model has following components, label with lines where the components are.**

supermassive black hole, accretion disk,
BLR (broad line region), NLR (narrow line region),
torus, galactic nucleus

- **Draw the relative size of a galaxy compared to the galactic nucleus, considering the overall shape.**
- **Is there more than one solution to the above question? Provide your reasoning.**

FIG. 2. The preactivity (top panel) and postactivity (bottom panel) questions given to participants.

working on assignments. Unlike a typical lesson plan, no guidance from a lecturer was provided and no intervention by an observer was made during group activities, except for distributing activity sheets and materials. The participants were entirely responsible for identifying problems, planning activities, and assessing the results.

D. Data collection

The data sources used in this study include the participants' written responses (i.e., answers to test questions), semistructured interviews, and nonparticipant observations of group activities [28,31]. Preactivity and postactivity test questions were developed (Fig. 2) and used to construct knowledge structures about active galaxies before and after the training program.

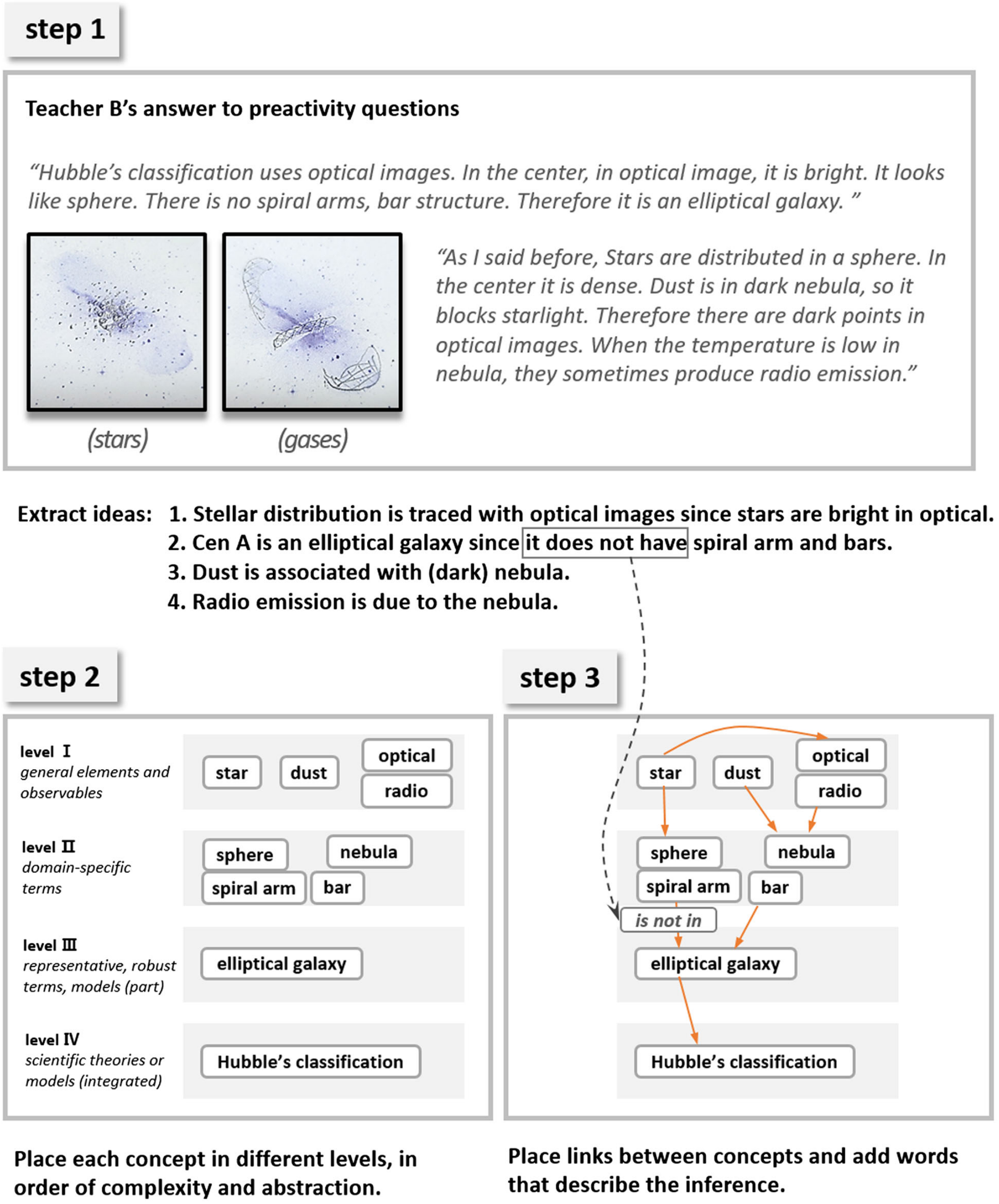
The pretest questions were validated using the content validity index (CVI, [32]), based on ratings by six external experts for each question. The developed post-test questions were reviewed by teachers who participated in the pilot program that was conducted during the development of the training program. The pretest and post-test questions had similar formats. The typical instructions to the participants were to (i) provide a written explanation of their interpretation, and (ii) make drawings of the expected phenomena. The writing and drawing are representation tools that are fundamental in teaching and learning science [33,34]. Therefore using such a format in pretest and post-test questions, it was expected that the participants' knowledge structures could be analyzed.

In addition to the preactivity and postactivity tests, two types of semistructured in-person interviews were carried out: postactivity and background interviews [28,35]. The postactivity interview involved double-checking the meaning of a participant's response, asking in-depth questions to understand the participant's thought processes that were not explicitly stated in the written responses, as well as soliciting the participant's reflections on the group activities. In the background interview conducted after the training program was completed, participants were asked about their teaching backgrounds, their orientations toward science teaching, and what they considered most important in designing their classes. Each interview lasted for approximately an hour. All the interviews were audiotaped and transcribed verbatim by the interviewer.

During the teacher training program, all the group activities were observed and videotaped, to determine how conversations between participants affected changes in the knowledge structure resulting from the group activity. The transcript of the conversations during the group activity was also used as a data source.

E. Data analysis

We followed three steps to create a visual representation of the participants' knowledge structures, as illustrated in Fig. 3 for Teacher B's knowledge structure before the program. The first step was to extract the facets constituting



Teacher B's answer to preactivity questions

"Hubble's classification uses optical images. In the center, in optical image, it is bright. It looks like sphere. There is no spiral arms, bar structure. Therefore it is an elliptical galaxy. "

"As I said before, Stars are distributed in a sphere. In the center it is dense. Dust is in dark nebula, so it blocks starlight. Therefore there are dark points in optical images. When the temperature is low in nebula, they sometimes produce radio emission."

Extract ideas:
1. **Stellar distribution is traced with optical images since stars are bright in optical.**
2. **Cen A is an elliptical galaxy since it does not have spiral arm and bars.**
3. **Dust is associated with (dark) nebula.**
4. **Radio emission is due to the nebula.**

Place each concept in different levels, in order of complexity and abstraction.

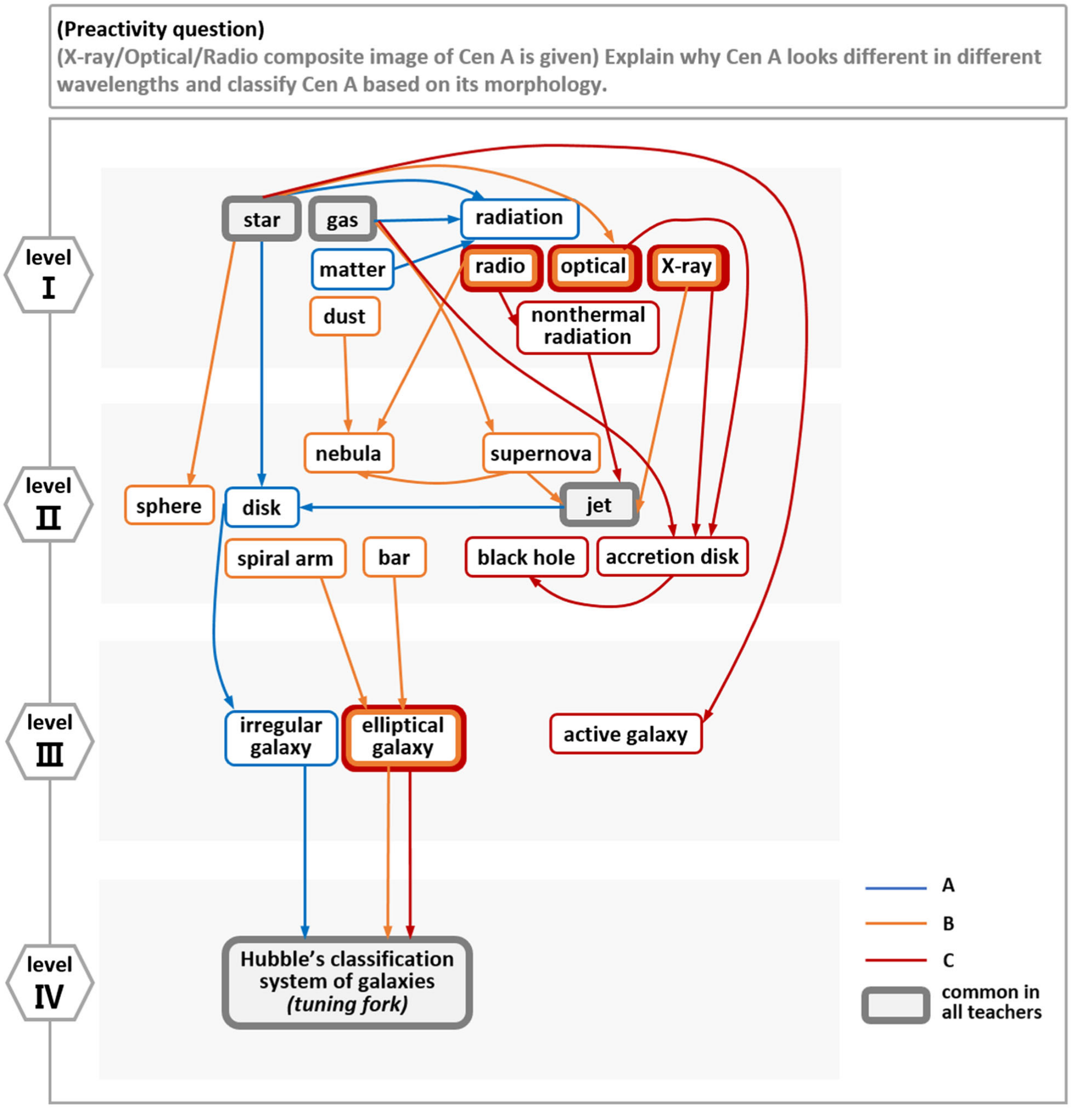
Place links between concepts and add words that describe the inference.

FIG. 3. Steps for constructing a visual representation of knowledge structures. Step 1 is facet extraction, step 2 entails organizing scientific concepts according to levels of concreteness and integrity, and step 3 involves forming connections between different concepts using words that describe key ideas.

a knowledge structure. The ideas and reasoning of participants were extracted from words or drawings in the responses to the pretest and post-test questions using the method described in Ref. [36]. All the extracted ideas were cross-checked through iterative comparison between different data sources, including answers to test questions and words from interviews [35]. Next, triangulation was performed using the two primary outcomes, and the data sources were analyzed separately by two researchers [31].

The next steps consisted of constructing a visual representation of the knowledge structure by listing the extracted facets as scientific concepts connected through reasoning in a similar form to a concept map [37]. In the second step, the concepts were assigned to four different hierarchical levels (Levels I, II, III, and IV) according to complexity and abstraction level, following the methodology presented in Ref. [38]. For instance, concepts generally used in astronomy, such as stars and dust, as well as concepts that express observable phenomena, such as radiation of different wavelengths, were assigned to Level I. Level II contained more specific concepts, particularly those within the domain of galaxy studies, such as the spiral arm and bar. Level III included representative elements, such as an elliptical galaxy, which could be defined through inferences using the concepts assigned to Levels I and II. Scientific theories or models that were transferable to other applications were assigned to Level IV.

The last step was to add lines connecting concepts to show the participant's reasoning [39]. The terms written in the linking arrows and the two connected concepts constitute


(Preactivity question)

(X-ray/Optical/Radio composite image of Cen A is given) Explain why Cen A looks different in different wavelengths and classify Cen A based on its morphology.

FIG. 4. Three teachers' knowledge structures about active galaxies before the group activity. The structures are represented as a network of concepts at different levels. The concepts are linked by lines that show connections between concepts. Concepts and links are color coded to represent different participants. Concepts associated with more than one participant are enclosed by two colored lines, and thick gray lines are used to represent concepts common to all three participants.

key ideas as propositions. For example, in the right bottom panel of Fig. 3, the connection between the “spiral arm” and “elliptical galaxy” represents the idea that “the spiral arm is not contained in the elliptical galaxy.” Figures 4–7 illustrate the visual representation of the knowledge structures constructed following the aforementioned steps.

III. RESULTS

A. Preactivity knowledge structures

Before presenting the changes in each participant’s knowledge structures on active galaxies, we present an overall comparison of the knowledge structures of the three participants in Fig. 4. In this figure, the concepts and connections between concepts are color coded to represent the different participants.

There were common characteristics among the three participants’ knowledge structures. First, all three participants had ideas about multiwavelength observations. The participants were aware of how the given images are obtained and could compare the shapes of the provided galaxy, Centaurus A (Cen A), at optical, radio, and x-ray wavelengths. Second, the participants considered the gas and stellar components of a galaxy to be equally important. The concepts of the “star” and “gas” were common to all the participants’ knowledge structures at Level I. Third, the participants identified a “jet” from the image of Cen A and attempted to draw inferences about the feature. Finally, the participants were able to use morphological characteristics observed in images and Hubble’s tuning fork framework to classify Cen A.

Despite these commonalities, the participants had different understandings of the physical processes associated with scientific concepts. For example, the responses of the three participants to the first pretest question on why Cen A appears different at different wavelengths are given below.

Teacher A:	Galaxies are composed of various types of matter, including stars and gas, and different types of matter produce different types of radiation.
Teacher B:	X-rays emission is from the jet, from the supernova, and radio emission is from nebula. Nebula are aftermath of a supernova and is composed of gas. Optical emission is from stars.
Teacher C:	Cen A is an active galactic nucleus, so it emits energy in different wavelengths. X-ray and optical emission is from gas in the accretion disk, where the part that is hotter produce x-ray. There are thermal radiation, while radio emission is nonthermal radiation from the jet.

Teacher A provided a robust explanation with an integrated view relating observable phenomena to existing components of a galaxy. Teachers B and C gave more complicated answers with a one-to-one correspondence between the wavelength and radiation mechanism. Teacher C was the only participant who explained the observations based on physical processes. Teacher C mentioned that a high gas temperature was required for x-ray emission, whereas radio radiation was nonthermal. The reason Teacher C tried to explain observations using physical processes might have been because Teacher C had taught active galaxies to high school students (11th grade). Several of the explanations found in the preactivity knowledge structures were not consistent with scientific facts; for instance, Teacher B considered a jet to be produced by a supernova.

Mutually contradictory ideas were occasionally found in the participants’ knowledge structures. All participants used morphology information from the optical image to classify Cen A as Hubble type and knew that optical emission is associated with stars. However, Teachers A and C provided inconsistent drawings and written descriptions of the stellar distribution.

Teacher A:	(classification) Irregular galaxy. (drawings of the stellar distribution) Stars are concentrated in the disk, because the jet is supposed to be ejected perpendicular to the disk.
Teacher B:	(classification) Elliptical galaxy, because of a round shape in the optical image. The galaxy has a bright nucleus, but no spiral arms and bars. (drawings of the stellar distribution) The density of stars is highest in the center (the bright part) of the galaxy. Stars are distributed spherically.
Teacher C:	(classification) Elliptical galaxy. (drawings of the stellar distribution) I don’t think there are stars in this object because of the black hole.

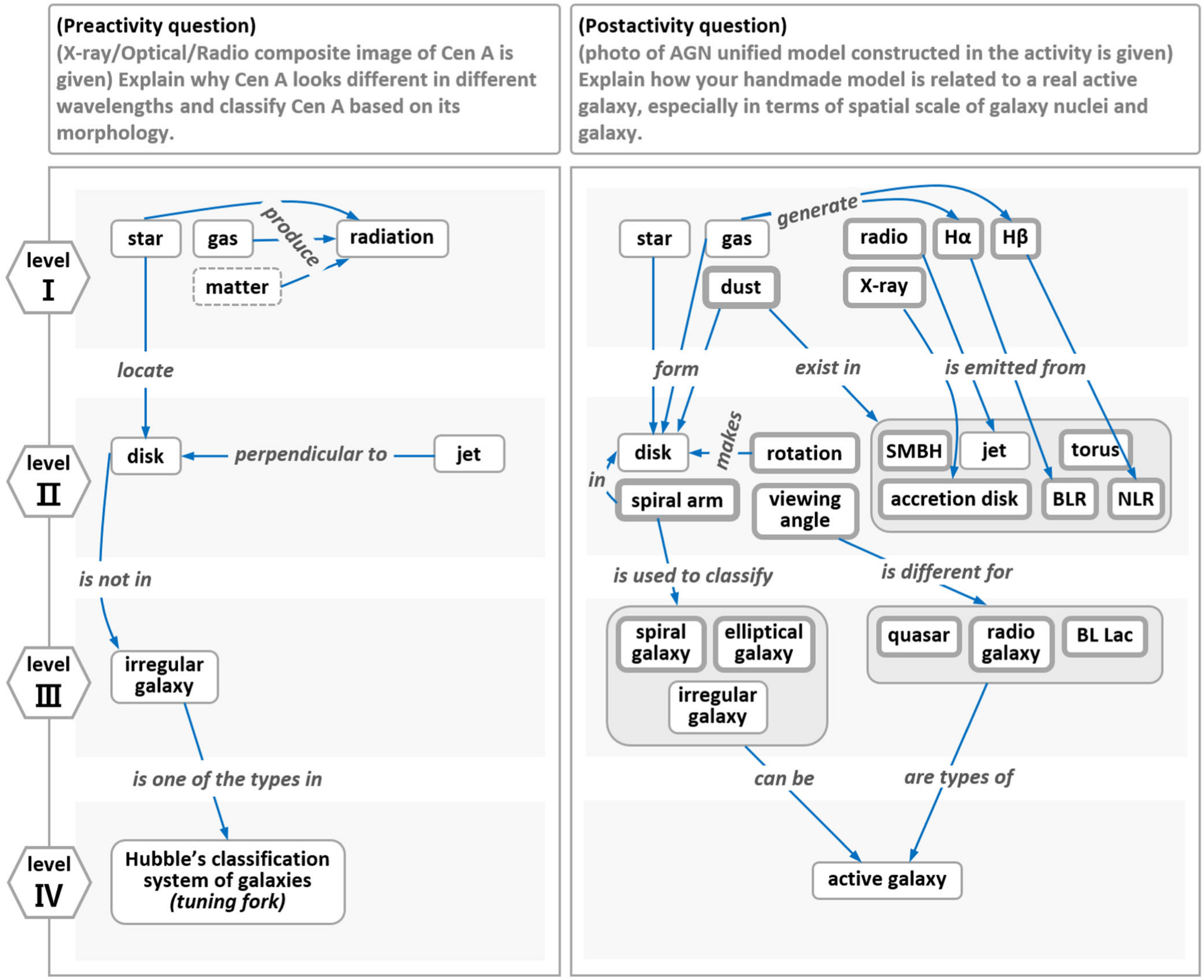
In summary, the participants’ knowledge structures contained many scientific concepts related to galaxies that were connected through reasoning. However, several ideas and inferences were inconsistent with scientific facts. The knowledge structures of the teachers contained contradictory ideas, indicating that low-level concepts were not completely integrated into higher-level abstract concepts.

B. Changes in knowledge structures

1. Case 1: Complete understanding of the subject

Figure 5 shows Teacher A’s knowledge structures before and after the group activity. The increase in the number of scientific concepts and inferences in the post-test answers and interviews relative to the pretest results show that Teacher A’s knowledge structure was elaborated by the activity.

At level I, specific words were used instead of general terms, for example, “radio” and “x-ray” rather than “radiation” and “dust” rather than “matter.” At level II, a cloud of scientific concepts for the components of the AGN emerged, including “supermassive black hole (SMBH),” “accretion disk,” “jet,” “broad line region (BLR),” “narrow



(Preactivity question)
(X-ray/Optical/Radio composite image of Cen A is given) Explain why Cen A looks different in different wavelengths and classify Cen A based on its morphology.

(Postactivity question)
(photo of AGN unified model constructed in the activity is given) Explain how your handmade model is related to a real active galaxy, especially in terms of spatial scale of galaxy nuclei and galaxy.

FIG. 5. Representations of Teacher A's knowledge structures before (left) and after (right) the group activity. Concepts that only existed in the preactivity structure are enclosed by the dashed line and concepts that newly appeared in the postactivity structure are enclosed by the thick line.

line region (NLR)," and "torus." The concepts in levels I and II were linked, demonstrating how different components of AGN dominate radiation at different wavelengths.

In addition to the cloud of concepts directly related to the outputs of the group activity, (i.e., building 3D models of AGN), another group of concepts related to galactic structures (such as the "disk" and "spiral arm") was identified at level II. These concepts were connected to level I concepts. This connection suggests that Teacher A had a well organized view of both the large-scale galaxy structure and the much smaller-scale nucleus structure explored in the activity.

Two aspects of galaxy structure at different spatial scales were summarized at level III. One concept cloud listed galaxy morphologies and the other consisted of different types of active galaxies. Inferences from these two clouds were combined at level IV, creating the concept of an "active galaxy." This result indicates that Teacher A had a complete and coherent understanding after the activity that active galaxies contain more active nuclei than normal galaxies.

2. Case 2: Improved but disconnected understanding

Figure 6 illustrates the knowledge structure of Teacher B before and after the group activity. Similar to the results obtained for Teacher A, a concept cloud consisting of AGN-related terms emerged at Level II after the 3D AGN model-building activity. Upon initial inspection, there appeared to be little change in the number of concepts Teacher B used to make inferences after the activity. Teacher B tended to rely on numerous connections between concepts in the preactivity knowledge structure, such as the

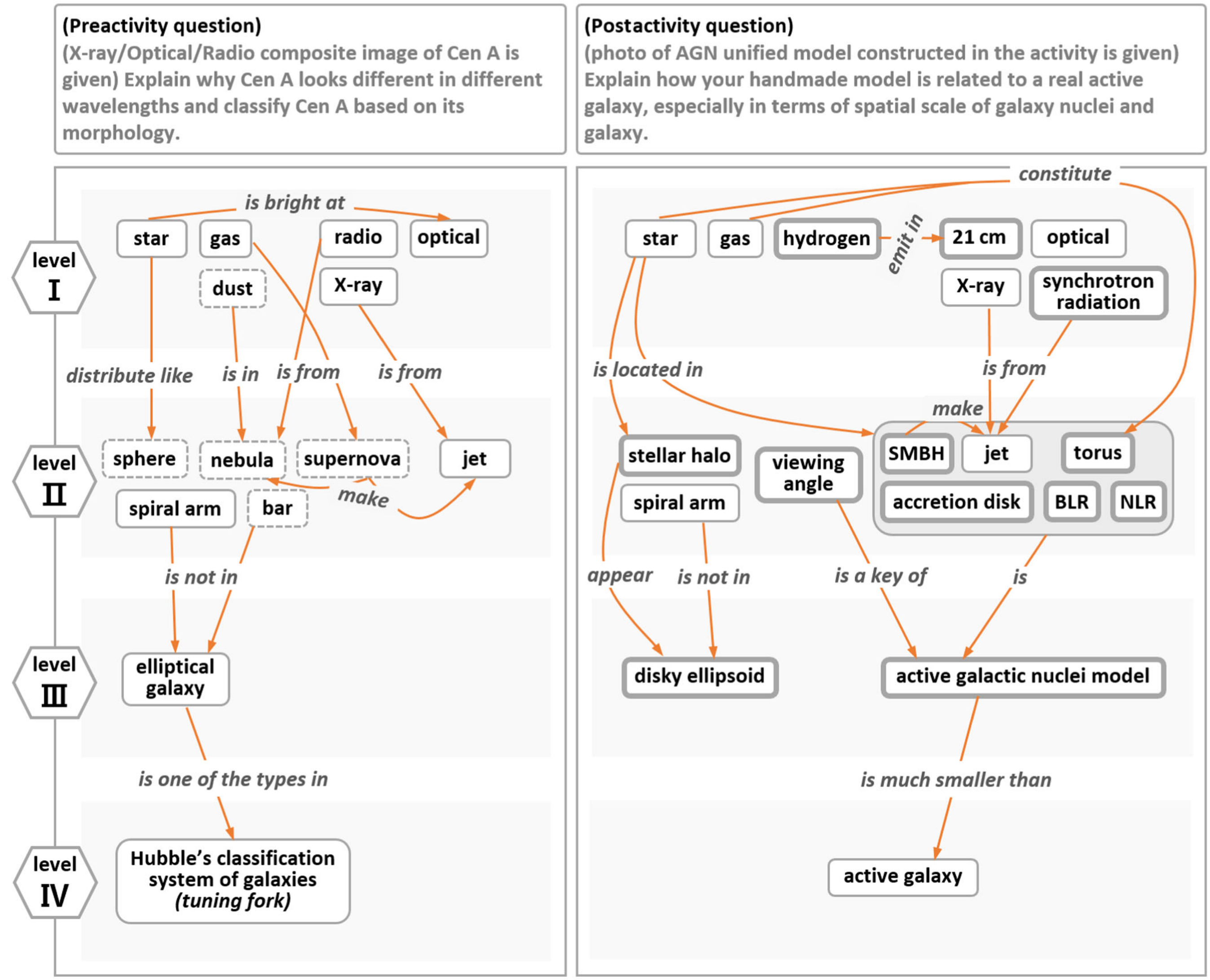


FIG. 6. Representations of Teacher B's knowledge structures before (left) and after (right) the group activity. Concepts that only existed in the preactivity structure are enclosed by the dashed line, and concepts that newly appeared in the postactivity structure are enclosed by the thick line.

idea that a supernova creates a nebula and a jet. The same trend was observed in the postactivity knowledge structure, such as the notion that a jet is powered by a SMBH.

Teacher B had a firm understanding of the stellar distribution reflected in the optical image and the morphological classification system before the activity, and this understanding persisted after the activity. However, in interpreting the constructed 3D model, Teacher B incorrectly identified a torus made of cotton balls as corresponding to stars.

Teacher B: Stars are distributed all over the galaxy. Some stars and ionized gas (well, the gas would be hot near the galaxy center) would form torus. Stars cannot be found near the accretion disk, because of hot disk and black hole. So stars would mainly be present in the outer part of torus we constructed.

Teacher B was aware that the spatial scale of the central nucleus of a galaxy is considerably smaller than that of the whole galaxy, although the actual analogy Teacher B employed was not quantitatively accurate.

Teacher B: A black hole is very small because its density is very large. So I imagine a galaxy would be much larger than a black hole. If a black hole and nucleus are the size of a ping-pong ball, a galaxy would be the size of the Earth, I guess?

As a result of misinterpreting the constructed model, Teacher B lacked conviction in the final conclusion about the morphology types of active galaxies.

Teacher B: The galaxy we built is close to elliptical… no… (hesitatingly) somewhere in between elliptical and spiral? Torus is very flat ellipsoid, because it rotates very fast. So if it is extended, a galaxy with an AGN would be

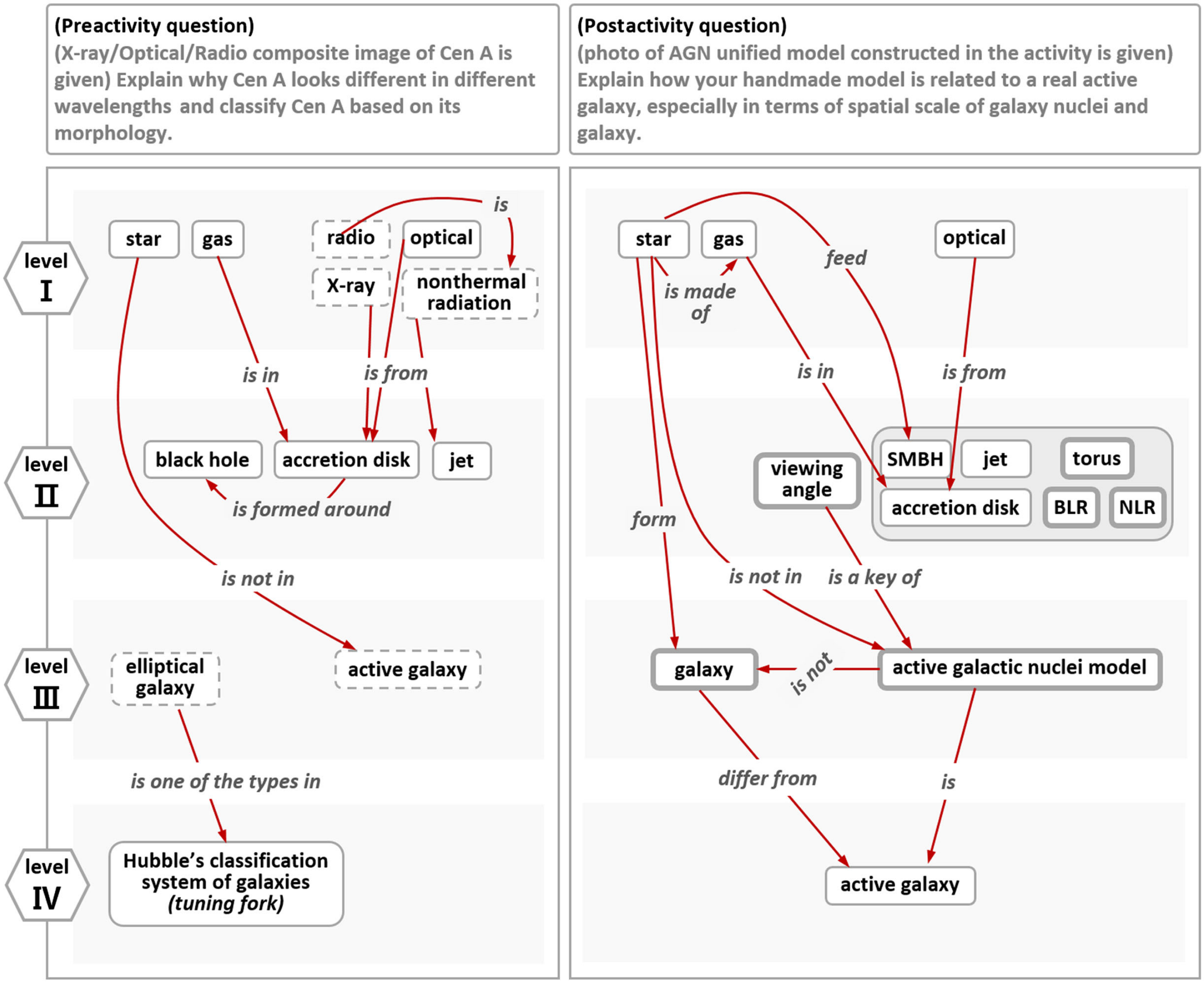


FIG. 7. Representations of Teacher C's knowledge structures before (left) and after (right) the group activity. Concepts that only existed in the preactivity structure are enclosed by the dashed line, and concepts that newly appeared in the postactivity structure are enclosed by the thick line.

closer to elliptical in shape while also being disklike.

There were two reasoning branches at level III of Teacher B's knowledge structure, one for the large-scale galaxy morphology and one for the small-scale AGN model. However, these two ideas were not coherently integrated into the "active galaxy" concept at level IV (the highest level). This disjointed knowledge structure persisted despite improvement and elaboration of the logical flows after the activity.

3. Case 3: Discordant understandings

The most distinctive characteristic of Teacher C's knowledge structure before the activity compared to those of Teachers A and B was a belief that there are no stars in active galaxies (Fig. 7). Even after the model-building activity and communication with the other teachers, Teacher C held onto the idea that stars cannot survive in active galaxies. The postactivity knowledge structure of Teacher C showed an improvement in inferences regarding stars and gas falling into a black hole and forming an accretion disk. The scientific reasoning of Teacher C that stars spiraling into the black hole would eventually be converted into gas and enable the black hole to grow increased the teacher's confidence in the conclusion that stars cannot coexist with an AGN.

Although there were no mutually contradictory concepts or ideas in the knowledge structure of Teacher C, no meaningful connection was established between the galaxy and AGN model, both of which were located at level III. Teacher C interpreted the 3D model as an object completely unrelated to a galaxy and was unable to answer questions about the model's spatial scale or the location of stars in the model.

Teacher C: We made a model of AGN. The model contains black hole, accretion disk, jet, and torus. Optical emission is generated from gas spiraling into the black hole. Well, the model is proposed to explain phenomena that appear different with a change in the viewing angle. But I don't think the AGN is a galaxy. It is just in a different category of objects. A galaxy is a group of many stars, but an AGN is not.

Ironically, the possible cause of the reasoning not being in line with scientific knowledge in Teacher C's knowledge structure could be the confidence in a firm understanding of the physical process of black hole feeding. Teachers A and B were aware of the relative scales of an AGN and the whole galaxy, i.e., a stellar system, which could have enabled Teacher C to grasp the idea that the AGN scale model they built was much smaller than a typical galaxy and could be located in the center of a galaxy. However, such communication did not occur because no discussion on these topics was suggested in the activity sheet.

IV. DISCUSSION

A limitation of this study is that the investigation of changes in knowledge structure is based on only one training session. Multiple training sessions may produce different results. However, we note that in practice, most in-service teacher training programs would consist of a single training session, which supports our discussion based on the data we collected. In addition to that, our result relies on the representation construction by teachers, in the form of writing and drawing, which is also affected by representation construction competence [33].

The changes in knowledge structures resulting from the activity (Figs. 5–7) varied with the participant. According to the information processing theory, a type of learning theory, learning occurs as a person receives new information and stores this information in the existing structure with enhanced connections and appropriate adjustments [22]. We list several factors below that affect learning, in the order of information processing.

A. Acceptance of information: Verbal interaction

Information is first entered into memory in the verbal or visual form [40]. In a group activity, information exchange in verbal form occurs frequently during conversations. The participants selectively accepted new information into their system. As was expected from the characteristics of group activity, cognitive conflicts that could enrich critical thinking [21] occurred through the conversations. The acceptance of new information into each participant's memory was dependent on whether a conversation was found to be satisfactory.

For example, in the following piece of conversation, Teacher C accepted new information provided by Teacher A because the explanations were considered to be useful for resolving Teacher C's initial question.

Teacher C: I would like to ask … (showing books to other teachers) so what is narrow or broad about line? A line width?

Teacher B: Yes.

Teacher C: So you are saying that Seyferts have broad emission line because they rotate very fast?

Teacher A: Here, near the black hole, there are clouds with broad emission lines. If we can see those because of the inclination angle, if our sightline is not covered by a torus, they are called Type-1 Seyferts.

Teacher C: I see. So that's the key point of the unification model.

However, if the person seeking an answer to a question did not find the discussion very useful, the provided knowledge was not accepted into the information processing system. An example is provided below.

Teacher C: I wonder, well, we know that a galaxy is made of stars. But (pointing the 3D model), are there stars somewhere around here? In the preactivity test, I was asked to draw the distribution of stars but I have never, ever thought about it. There is a black hole, and a black hole can suck everything in, so if there had been a star, the gas that constitutes the star would have been swallowed by the black hole. So there would be NO stars. I think this is the difference between active and normal galaxies.

Teacher A: Do you mean that no stars exist in active galaxies?

Teacher C: Well, I'm not sure, but it appears that no stars can survive and appear bright in this structure.

Teacher B: I agree with you, C. I found a picture on the Internet of the AGN model that (showing the picture) does not have a stellar component.

Teacher C: Yes. This picture shows visible radiation, but this radiation is from heated gas, not from stars.

Teacher A: I have a different view. Consider the fact that we can observe hydrogen emission lines here. There must be hydrogen all around here. This means that star formation can take place somewhere in the galaxy. But this picture is focused on the structure around the black hole. So stars are there, but it's just that stars are not drawn here.

Teacher C: You may be right, but I'm not quite convinced.

Teacher A responded to the issue Teacher C raised about the AGN host galaxy by providing information that was in conflict with Teacher C's previously established idea and more in line with existing scientific knowledge. However, Teacher C did not consider Teacher A's argument to be sufficiently persuasive and therefore ended the conversation without accepting the new information into the existing knowledge structure. This problem can frequently occur in a group activity that does not involve a person with expertise in the subject matter. Instead of providing indirect evidence (i.e., the existence of hydrogen) to support the existence of stars, a comparison of spatial scales may have provided Teacher C with a reasonable explanation of why stars can exist in a host galaxy of an AGN. A successful conversation is required for learning to occur. For a conversation to be successful, discussions should directly address existing misconceptions.

B. Storing information: Preferred pattern

The externally acquired new information was integrated into the existing knowledge structure using the same reasoning framework. Therefore, the characteristics of the knowledge structures were not changed considerably by the group activity.

For example, Teacher A's preactivity knowledge structure was simple and concise. The group activity of building a 3D model of an AGN mainly updated Teacher A's knowledge structure by the addition of new concepts and links in a concise and organized manner. Elaboration and organization are elements that facilitate the encoding of information in a knowledge structure [22], which was consistent with Teacher A's learning process.

On the other hand, there were many links between concepts in the preactivity knowledge structure of Teacher B. Teacher B tended to explain phenomena by using as many concepts as possible and used logical reasoning to connect different ideas. In Teacher B's postactivity knowledge structure, new concepts related to the AGN were linked to each other, and some ideas that were not in line with scientific consensus were replaced. The increase in the number of links to the schema structure played the most significant role in Teacher B's learning process.

For Teacher C, some individual links between concepts became stronger because Teacher C values the use of sequential processes for explanation. Teacher C's idea of the absence of stars in a galaxy was supported by an ordered sequential explanation of a black hole swallowing gas and stars. Therefore, preexisting contradictions about the AGN and galaxies in Teacher C's knowledge structure could not be resolved. New information about AGN host galaxies was not accepted into Teacher C's knowledge structure and even the information that was accepted was not sufficiently meaningful to produce a rearrangement in the existing structure. Consequently, learning was inactive for Teacher C.

C. Basis: Orientation to science teaching

The basis of changes in knowledge structure is the preexisting framework of individuals (Sec. IV B), such as conciseness (Teacher A), a tendency to rely on links (Teacher B), and valuing sequence reasoning (Teacher C). These characteristics are mostly influenced by participants' orientation to science teaching. Orientation to science teaching is related to teachers' perspectives on their roles and students' attitudes in class, as well as teachers' beliefs about what constitutes a good explanation. Therefore, in this teacher training program, the teachers' perspectives on the activity and their attitudes during conversations were observed.

Among the three teachers, Teacher A had taken college-level astronomy classes most recently. Therefore, Teacher A could quickly consult appropriate references, such as Internet resources or literature, to resolve the issues that were raised during the group activity. Teacher A appeared to be happy in the role of troubleshooter or problem solver for the group. This role aligned with Teacher A's orientation to science teaching because Teacher A's self-definition in the in-depth interview was as a helper or assistant in the classroom.

Teacher A: I expect students to be active in class and not to passively sit and listen to the teacher. I let them play on the ground I prepare, and if they can find answers to questions themselves, that would be the best class I could dream of. I am happy to be a guide or helper on their journey.

Since Teacher A acted as a "helper" or assistant to the group during the training program, Teacher A's communication with the other participants was passive. Teacher A interacted with the group by mostly answering questions and did not try to refute arguments or opinions challenging the logic. As a result, Teacher A's knowledge structure was mainly changed by information from references and not through interaction with the other participants.

Whereas Teacher A's updated knowledge structure was concise and clear, Teacher B's postactivity knowledge structure was full of links between different concepts, some of which were not in line with the scientific consensus. This large number of links in the knowledge structure was consistent with Teacher B's preference for using contextual explanations in class to improve students' understanding of scientific concepts. Teacher B attempted to provide explanations whenever possible and considered an explanation to be more valuable than an accurate understanding of concepts.

Teacher B: How do you define knowledge? I prefer constructive views of scientific knowledge. I agree with the idea that we need to teach students scientific knowledge that everybody accepts or agrees with. Still, many hypotheses considered wrong today may later turn out to be true, and theories are still developing. So I would like to present all possibilities to students. Teaching students how to explore and investigate problems is much more important than teaching concepts. Well, students may need to know facts to take a college entrance exam, but for their future, students need experiences to inquire and get answers.

Teacher B was the most active member during the group activity and naturally was a "leader." In the dialogues, Teacher B was the person raising questions, though not always expecting to get answers. Teacher B tended to rely on existing content knowledge first to solve problems, instead of utilizing the newly obtained knowledge by getting answers to the raised questions [41]. This tendency resulted from Teacher B being interested in finding a low-level connection between concepts (that can be easily assimilated by young students) than in developing a consistent framework to describe all the relevant facts. Consequently, after the group activity, two large branches of inferences about the galaxy and AGN were established in Teacher B's knowledge structure but were not combined into a single coherent framework.

Teacher C's knowledge structure after the group activity showed a segregation between the terms of a nucleus and host galaxy, even though Teacher C's inferences about physical processes feeding a black hole had been strengthened. During the group activity, Teacher C typically was a "checker," and double-checked the other participants' intended meaning by asking for an explanation of the new concepts. Teacher C attempted to ensure that where the understanding of the new concepts was correct, which was strongly related to Teacher C's orientation to teaching, that is, teachers should provide students with accurate knowledge.

Teacher C: I prefer students who absorb what I teach as it is. Likewise, I believe teachers should only give students accurate information. Teachers should not introduce information they are unsure of.

Teacher C preferred classes in lecture format, unlike the other two teachers who preferred student-centered classes. Teacher C was interested in gaining accurate scientific knowledge through the teacher training program to increase the confidence in teaching students. Teacher C continuously checked new knowledge about the AGN unification model (Fig. 1), thereby strengthening the inferences from scientific concepts. However, Teacher C did not receive a sufficiently accurate explanation about the spatial scale of an AGN and its host galaxy. Thus, concepts about host galaxies were not properly assimilated [42] into Teacher C's existing knowledge structure. Teacher C described the preferred knowledge acquisition process during the background interview conducted after the training program, as reproduced below.

Teacher C: I feel less confident about astronomy than geology or meteorology. I didn't receive lectures on galaxies or cosmology when I was at university. So I perform Internet searches to prepare for my classes because it takes too long to read and summarize books. My best memory of an astronomy-related lecture is the qualification training (mandatory for early career teachers in Korea) that I took almost 10 years ago. The professor explained so many concepts and physical processes in a very convincing manner. I still consult my notes from that lecture.

If a convincing explanation by a person in authority was given to Teacher C, Teacher C could have been persuaded to bring the inconsistent inferences in the knowledge structure into coherence. However, it is not necessary that "a person in authority" is an expert in the domain such as a researcher or professor. Teacher C had a positive remarks about learning through nonguided group activity.

Teacher C: I actually don't like inquiry activities, especially using hands, scissors, glues… but despite that, I felt good. Nobody in our group had 100 percent of knowledge about the subject. One person knows this much, and another person knows that much… It was like we were compensating some missing points from others' help.

Teachers A and B could have provided convincing explanations to Teacher C since they had ideas about spatial scale comparison between the nucleus and host galaxy, but unfortunately, they were not able to identify Teacher C's cognitive conflict.

V. CONCLUSION AND IMPLICATIONS

Rapid research updates followed by ongoing and future astronomy surveys, space missions, and theory development are expected to increase the demand for training programs enabling in-service teachers to understand and apply cutting-edge research results. A training session in the form of a nonguided group activity was used as an alternative to the traditional lecture-style program in this study.

Changes in the knowledge structures of three in-service science teachers resulting from the program were identified. These changes indicated that the teachers had undergone a learning process, where newly acquired information was selectively accepted and integrated into their preexisting thinking framework [42]. The learning is motivated and encouraged by the cognitive conflicts during the conversation between participants [21], and the process can be explained with information processing theory (RQ1). During the program, new information about scientific subject matter and inferences was provided to individuals through conversations with other participants. The obtained information was then selectively accepted into the participants' knowledge structure through the encoding process, where elaboration and organization played significant roles. Links with the embedded schema structures were strengthened. The factors that affected the teachers' learning included the meaningfulness of the conversation, the individuals' pattern of encoding information, and finally, the individuals' orientations to science teaching, which were the basis for their existing frameworks and attitudes toward the activity (RQ2).

The amount and direction of learning varied among the teachers. The limitation of the nonguided group activity, i.e., the participants should only rely on their own alternative conceptions to go through the cognitive conflicts, weakened the effect of learning especially for Teacher C. Although Teacher C acquired new information during the activity, such information was not properly encoded and stored in Teacher C's knowledge structure. One possible way of changing Teacher C's knowledge structure could be to provide specific discussion items, for example, "Compare the size of the AGN to the size of the host galaxy," or "Linearly scale the size of the AGN model to that of the Milky Way galaxy." Such clear guidance would make it easier for participants to gain new understandings while feeling autonomous.

Therefore, in response to RQ3, we suggest two revision strategies to the currently developed training program. (i) The addition of a step to construct a representation of the participants' CK before and after the teacher training program. (ii) The addition of discussion items in the activity sheet based on a consultation with an expert in the domain CK. Participants could visualize their CK of the subject using schema for constructing a concept network [43]. This visual representation, especially the preactivity representation, could be reviewed by an expert in the subject matter knowledge and necessary discussion items could be added to the activity guide sheet. Within this strategy, the expert would not need to be present during the group activity to instruct the participants. Constructing a visual representation after the activity would also be useful during the review stage for participants to review their own learning and recognize how students will learn from their instructions. This training would help in-service teachers design their own classes with greater confidence in astronomy education.

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