“It’s a lesson with no correct answer”: Design issues in preservice teachers’ use of history of science for lesson planning

Wonyong Park, University of Southampton, w.park@soton.ac.uk
Sibel Erduran, University of Oxford
Jinwoong Song, Seoul National University
Minchul Kim, Kongju National University

Abstract

While many recent curriculum reform documents worldwide recognise the value of history of science (HOS) in science teaching, in-depth investigations into teachers’ experiences of planning HOS-based science lessons have been rare. We present a case study of two groups of preservice science teachers (PSTs) who used HOS to collaboratively plan high school science lessons. The research aims were to understand what design issues arose and how they unfolded as each group planned the lesson. A design issue arises when group members dispute over a topic related to lesson planning and there is a need for decision making. Our analysis of multiple data sources collected throughout the semester pointed to several major design issues around *selecting a suitable history, adapting history, teaching a topic with no correct answer, balancing science and history, and empathising with people from the past*, which manifested differently across the two groups. PSTs’ reflections suggested that the collaborative planning experience helped them understand the limitations of content-focused pedagogical methods in planning HOS-based lessons and recognise various ways HOS can be used to enrich science teaching. The study sheds light on some challenges of PSTs when planning an unfamiliar type of science lesson and how a collaborative lesson planning experience can create opportunities for broadening their knowledge of science lesson planning.

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1. Introduction

Collaboration among preservice teachers in teacher education settings has drawn much attention from teacher educators (Akiba et al., 2019; Cochran-Smith & Lytle, 1999). Empirical studies have found that collaborative lesson planning leads to teacher learning and change in practice when external support is appropriately provided (Voogt et al., 2011). Planning a lesson in collaboration with peers can be helpful for PSTs who are not experienced in lesson planning, especially when using teaching approaches that are not familiar to them, such as history of science (HOS). It has been argued that HOS is beneficial to science instruction and thus should be included in science teacher education (Matthews, 2014; McComas, 2014). For example, Allchin (2013) illustrated nine ways HOS can benefit science teachers: contextualising and motivating science learning, clarifying concepts, revealing misconceptions, celebrating intellectual achievements, promoting science as a possible career for students, developing students' inquiry skills, profiling the nature of science (NOS), highlighting the social dimension of scientific research, and portraying the cultural contexts of science. Such benefits have given rise to a strong research tradition in science teacher education to utilise HOS for these purposes (Heering, 2009; Lewthwaite et al., 2012; Matthews, 2019; Park & Song, 2022; Riess, 2000). It is easy to find in curriculum reform documents published over the past few decades recommendations on the use of HOS for science instruction (Eurydice, 2011; NGSS Lead States, 2013; MOE, 2015).

However, using HOS can be challenging for novice teachers, given the nature of history that relies on reconstruction and interpretation of human actions, meanings and intentions, which may be seen as contradictory to the content knowledge of science that is typically the focus of science lessons and tends to be portrayed as objective and certain. With such complexities between history and science in mind, this study focuses on the use of HOS in science lessons and particularly how a collaborative planning experience over a semester can support PSTs' knowledge and reveal some challenges that they face. Although there has been sustained interest in incorporating HOS in science lessons that can bring a range of benefits to science learning (Allchin et al., 1999; Heering, 2000; Matthews, 2014), little is known as to what specific issues can emerge as PSTs engage in lesson planning using HOS. Investigating such issues may give insight into PSTs' subject knowledge and epistemological orientations, among others, which may help teacher educators plan their own teaching with PSTs.

We report on an empirical study carried out in a university teacher education course. In this study, we understand lesson planning as a process of deliberation, that is, as described by Reid (1979), 'an intricate and skilled intellectual and social process whereby, individually or collectively, we identify the questions to which we must respond, establish grounds for deciding answers, and then choose among available solutions' (p. 189). Interpreting the lesson planning process as deliberation allowed us to clarify what the issues were and how the participants reached a solution, which could provide insights for preparing teachers for HOS-based science lessons. The research question was: *What are the key issues that PSTs face as they engage in collaborative lesson planning using history of science, and how do the issues manifest in the two groups?*

2. Literature Review

2.1. Collaborative curriculum design

In this paper, we analyse PSTs' lesson planning through the lens of collaborative curriculum design. The idea of collaborative curriculum design is gaining increasing attention in teacher education (Voogt et al., 2015). Design teams can be viewed as a specific type of professional learning community with the aim to (re)design curricula or educational materials (Binkhorst et al., 2015; Kafyulilo et al., 2016). Collaborative planning is important in line with the sustained emphasis on the role of teachers as key agents in curriculum design (Clandinin & Connelly, 1992; Priestley et al., 2015). A major benefit of collaborative planning experiences is that they can help teachers effectively design educational materials and implementation of them. A number of studies have provided evidence that a collaborative planning experience can promote teachers' professional development through sharing each other's lesson-related knowledge and skills (Voogt et al., 2015).

Building on Schwab's earlier idea of deliberation, where different viewpoints, values and beliefs are discussed and negotiated amongst stakeholders (Schwab, 1969), Walker (1971) argued that the curriculum design can be understood as a process of deliberation. Each participant in curriculum design would have personal beliefs and values as to what the curriculum should achieve and look like, which brings about deliberation that clarifies important issues, possible design options and their costs and benefits (Walker, 1971). This model of curriculum development is particularly useful for describing the process of curriculum planning within a group (Misco, 2007; Reid, 2009). In particular, the deliberative approach to curriculum centres teachers' agency in debating, deliberating and deciding what and how to teach in the classroom (Shulman, 1984).

Within science education research, there have been studies that used collaborative lesson ? planning in in-service teacher professional development settings (Hancock et al., 2019; Millar et al., 2006; Mooney Simmie, 2007). In a study by Kafyulio et al. (2015) where science teachers in two schools collaboratively designed technology-enhanced science lessons, it was found that the design experience, classroom implementation and reflection resulted in the participants' improved knowledge of technology integration in science teaching. Research on collaborative curriculum design suggests that an appropriate level of support such as the provision of sample materials is useful in guiding the teacher teams (Binkhorst et al., 2015; Huizinga et al., 2014).

Currently, there are at least two gaps in the literature on collaborative planning by teachers. First, since collaborative curriculum design began as an approach to in-service teachers' continuing professional development, relatively less is known about preservice teachers' collaborative planning process. Also, there is a lack of focus in subject-specific issues in collaborative curriculum design. More specifically, most previous research on collaborative planning focused on discipline-general pedagogical issues such as technology integration (Kafyulio et al., 2015), while there are relatively few studies on issues specific to science education, such as the use of HOS. Although science educators have long advocated the teaching and learning of HOS in science lessons (Allchin et al., 1999; Matthews, 2014; Seroglou et al., 1998), empirical studies on PSTs' engagement of integration of HOS in their lesson plans are limited.

2.2. Using history of science in science lessons

Science educators and curriculum reform documents have long advocated the use of history in science instruction (AAAS, 1990; Justi & Gilbert, 1999; Klopfer, 1969; Wang & Marsh, 2002). According to Matthews (2014), HOS is can support learners' comprehension of scientific concepts, methods and NOS; to make connections between the personal process of conceptual development and historical trajectory, and between diverse science disciplines; and also to be of intrinsic value as a reflection of the human culture. Such potential values of HOS in science teaching inspired educators to incorporate HOS in various levels of school science and teacher education programmes (Abd-El-Khalick & Lederman, 2000; McComas, 2008). Studies have focused on, for example, the presentation of HOS in science textbooks (Irwin, 1996; Leite, 2002), the use of historical experiments in science lessons (Cavicchi, 2008; Chang, 2011; Heering, 2003), the integration of HOS into teacher education (Abd-El-Khalick & Lederman, 2000; Etkina, 2010; Gandolfi, 2021; Howe & Rudge, 2005; Park & Song, 2022; Winrich & Garik, 2021), utilising various case histories from different historical periods and regions.

At the same time, obstacles to using HOS in science teaching have been reported. Höttecke and Silva (2010) pointed out that (a) The disciplinary culture of science (especially physics) that focuses on imparting truths about nature undermines the historical and changing nature of science; (b) Science teachers feel unsafe about teaching science as a process and often do not have an informed understanding of nature of science; (c) Science curricula rarely include HOS as an explicit teaching goal; and (d) Science textbooks reinforce the naïve and linear view of scientific progress and do not connect content knowledge and HOS. In Henke and Höttecke's (2015) study with German expert physics teachers, a range of challenges were reported such as finding and adapting teaching materials, knowing and applying instructional design principles suitable for HOS lessons, motivating students with HOS, addressing students' naïve conceptions about HOS, using open-ended historical classroom activities in the light of known outcomes, teaching modern science concepts using historical investigations, designing and enacting assessment tasks that can target HOS, and justifying the inclusion of HOS against curriculum and colleagues. In addition, oftentimes, teacher educators have a limited background in HOS, making it difficult for them to incorporate HOS in teacher education courses (García-Carmona, 2022). These obstacles indicate that although HOS can bring many benefits to science teaching, tensions can arise between the traditional, content-centred approaches to science teaching and HOS-based approaches.

Despite the long interest in the role of HOS in science learning (Matthews, 2014; Riess, 2000; Winrich & Garik, 2021), there is currently limited understanding as to what challenges and issues can arise for novice teachers as they plan a lesson based on topics in HOS, particularly in collaborative settings. Our study aims to address the gap through a close examination of two groups of PSTs who developed fairly distinct HOS-based lessons. The analysis will reveal how the issues unfolded differently across the groups due to the different purposes and methods of using HOS in science lessons.

3. Methods

3.1. Context of the study

The study took place during a one-semester course in the four-year preservice science teacher training program at a large research university in Seoul. In Korea, science teacher preparation is mainly based on undergraduate programmes consisting of subject knowledge (physics, chemistry, biology or earth science) courses, education theory courses, science methods courses, and a short school placement for a month (Kwak, 2019). The course in focus for this study was 'History of Science for Teachers' and was delivered in the Fall 2018 semester. The third author was the main instructor, and the first author participated in the course as one of the two teaching assistants (TAs). The course aims were to develop PSTs' knowledge of HOS across periods and regions as well as their skills to use HOS in science instruction. Over 15 weeks, the course covered both conceptual and sociocultural development of science in different periods and regions. Table 1 summarises the course content and the data sources.

[Insert Table 1 here]

Throughout the semester, PSTs worked in groups of two or three to develop a 50-minute unit. Their tasks were to select the scientific and historical content of the lesson, develop a lesson plan, and then demonstrate it in a short microteaching session (20 mins) where their peers acted as imaginary students. The study participants were eight PSTs enrolled in the course (Table 2; names were changed to maintain confidentiality). The participants came from physics, chemistry or biology education backgrounds and were varied in their years of study. The university's science teacher education programme included both scientific content courses (70%) and education theory and practice courses (30%) distributed over four years, meaning that the participants had different levels of knowledge in both science and education according to their university years. Participants were split into three groups, and each group was deliberately made heterogeneous in terms of their years of study, genders and subject specialisms. This was to facilitate constructive conversation by bringing together PSTs from a range of different backgrounds and experiences.

[Insert Table 2 here]

The groups' lesson planning process over a semester was analysed based on the multiple case study approach (Yin, 2017), and each group consisting of three PSTs was considered a case. Two of the three groups, Group 1 and Group 2, were selected as focal groups for analysis. The selection of focal cases was based on two major considerations, aligned with our research aims to explore the planning process in-depth. First, the two groups were in good contrast in terms of their selected lesson topic and instructional approaches, which enabled delving into different aspects of the curriculum deliberation process using HOS. Specifically, Group 1's focus was on the epistemic and methodological aspects of science, while Group 2 focused on social and cultural aspects of science, which corresponds to different domains of NOS (Irzik & Nola, 2011). Second, after observing two design conversations between Weeks 5 and 6, these two groups were identified by researchers as potentially information-rich and 'excellent' cases that would provide quality information about the phenomenon under investigation, namely their collaborative planning experiences (Morse, 2007; Yin, 2017). Their reflective writings and class participation suggested that they were reflective about each stage of the curriculum deliberation and thus were able to speak fluently about their experiences. Although data were collected from all three groups during the semester, based on a review of collected data after the semester, it was decided that the two focal groups would be invited for interview and included in the analysis due to these reasons.

Throughout the semester, the instructor and teaching assistants closely tracked the groups' lesson planning process. Given that research on collaborative curriculum design emphasises the need for external support (Binkhorst et al., 2015; Voogt et al., 2016), we organised one informal tutorial session with each group to discuss their plans, issues and challenges. Feedback was also provided by instructors and peers at the mid-term presentation of lesson plans. The support from the teaching team was limited to providing general advice and helping to find relevant materials and asking questions for groups to consider; No specific suggestions regarding design issues or decisions were offered, as we believed deliberating on these aspects between the group members would create learning opportunities for PSTs.

3.2. Data collection

Multiple data sources collected throughout the semester were used for the study. Between Week 5 and Week 13, the groups were given 40 to 60 minutes of time for their group work at the end of each lecture. The group discussions were audio-recorded to understand the process of lesson planning (7h 28m in total). Participants also completed written reflections and feedback in Week 8 and Week 15 about their learning from the course. On Week 8, the TAs had a tutorial session with each group to offer help and comments and at the same time gain some understanding of participants' experiences while planning the lesson. The tutorial sessions were audio-recorded (1h 33m in total). The mid-term and end-of-term presentations of lesson plans with peer feedback discussion were also audio-recorded (2h 30m in total). Field notes produced by the TAs, presentations, videotaped microteaching sessions and other course artefacts were collected and used for analysis and interpretation.

Four PSTs were selected based on their active engagement in the course and then were invited for an interview of around an hour (3h 43m in total). As we were more interested in understanding the collective decision-making processes in the two groups than comparing individuals' experiences, four PSTs were considered sufficient for obtaining necessary information. All interviews were co-conducted by two class TAs, following interview protocols that included general questions about their learning from the course content and lesson planning, but these protocols were adapted before each interview by adding specific questions based on their group work, previous responses or assignments. An ethics approval for this study was granted from [university name] [approval number]. At the beginning of the course, participants were informed of the purposes and processes of the study, assured of anonymity and their right to stop participation, etc. Every individual interview, which did not comprise the coursework, was conducted with additional consent after the final course grades were awarded.

3.3. Data analysis

Our data analysis centred on the recordings of design conversations, which refers to teachers' verbal interactions where problems about lesson planning are identified, framed, discussed and resolved (Boschman et al., 2014). We started by condensing the data to make meaningful aspects of it more visible (Miles & Huberman, 2014). The first step for condensation was to summarise the recordings of conversations in the form of flow charts (Ash, 2007) that catalogued each group's process of lesson planning from start to finish. The use of flow charts was deemed appropriate for capturing the key events in each group's lesson planning process and how they develop over time. It enabled capturing how the lesson plan as a central object is shaped, deliberated and revised over time. Two researchers individually listened to the entire audiotaped design conversations of each group to generate a draft flow chart, and this was refined after the other researcher listened to the audio again to confirm that all key events were presented. Throughout this process, other data sources were read laterally to gain a full understanding of the contexts and nuances of the conversations. Combining the insights from this initial analysis and the theoretical model of curriculum development (Walker, 1971), we were able to develop an analytical framework **(Figure 1)** that captures some elements of deliberation (design issue, discussion, proposal of ideas, resolution, etc.). Using this framework, the flow charts were segmented and organised into design episodes, each consisting of a design issue, a process of deliberation and a design solution.

Seventeen design episodes were identified from the two groups' design conversations. A design episode began with 'design issue' (e.g., selecting a suitable history, balancing history and science). A design issue arises when group members dispute over a topic related to lesson planning and there is a need for decision making (Walker, 1971). Each issue involved either making a decision among multiple choices or resolving a particular problem, or sometimes both. For example, there were issues around whether to connect HOS and NOS at the beginning or end of the lesson, and whether to include an experiment in the lesson or not. Once a design issue was on the table, one or more options were suggested by team members, each with some supporting rationales. If there were multiple options to choose from, they collectively reached a decision on some reasons why one option was better than the rest. Some design episodes occurred in an incomplete or more complicated structure, but most times, this model was enough to capture major design issues and how it was resolved. A design episode ends by reaching a decision that resolves the issue or changing the subject to another issue without resolving it.

[Insert Figure 1 here]

Once the design conversations were chunked into design episodes, and a list of issues was compiled, we read through the interviews and written reflections again in light of the design issues identified in order to develop a fuller understanding of each issue, the interconnections between issues, and the comparisons between researchers' and PSTs' interpretations of each issue. This process helped triangulate the analysis by incorporating different viewpoints on the lesson planning process. Based on the coding result, comparisons and contrasts were made across the two groups. Design issues from the two groups were aggregated into five broad categories, with questions such as 'Why was this a problem?', 'What aspect of lesson planning (content selection, sequencing and organisation, pedagogical strategies) is this issue concerned with?' in mind. Lesson plans, materials, and presentation recordings were used to gain a better understanding of the groups' intentions and decision-making processes. Two authors co-developed initial categories of issues in each group through multiple iterations of analysis and comparison and listening to the recorded group discussion together. These categories and emergent themes within categories were later checked by the other authors for consistency and reliability.

4. Results

4.1. Overview of developed lessons

As noted earlier, the lessons developed by the two groups demonstrated two distinct ways of incorporating HOS into science lessons, as summarised in Table 3. Group 1's lesson focused on teaching the gas laws to twelfth-grade high school students. They initially planned to include an activity where students replicate the experiments by Boyle and Charles to help them recognise the discrepancies between prediction and observation, which would then lead to a discussion about the process of science. However, due to some practical challenges to conducting the experiment in the school setting (to be elaborated in Section 4.3), the group switched to simply presenting the data from the experiment to students so that they could work with the data without having to generate it (**Figure 2**). The students would then discuss the discrepancies in the group and share with the class what the process reveals about NOS. The group intended to teach how scientific theories are corrected and improved through comparison with empirical data, but they were open to discussing other aspects of NOS if identified by students from the activity.

[Insert Table 3 here]

While Group 1 focused on the historical development of a specific content area in chemistry, Group 2's focus was to highlight how the benefits and risks of nuclear physics can be reliant upon the values that individuals and societies hold at a certain time, for eleventh-grade students. After a brief introduction to nuclear physics by the teacher, the lesson consisted of two main parts: a historical role play and a contemporary debate. In the role play, students would play specific roles that were based on the debates around nuclear weapons during World War II by key stakeholders (**Figure 3**). These roles reflected conflicting interests and perspectives on the development and use of nuclear weapons in the midst of the World War. After students discuss the social aspects of science, they would move on to the contemporary debate where different stakeholders (a non-governmental organisation, scientists and government) discuss whether to continue building new nuclear power plants. After these activities, the students would share their reflections on how science interacts with sociocultural contexts, and the value of scientific knowledge (i.e., nuclear physics) can be interpreted differently across different contexts.

[Insert Figure 2 here]
[Insert Figure 3 here]

Table 4 summarises the design issues that the two groups faced during their lesson planning. The first three issues emerged in both groups but in different ways due to the different roles of HOS in their respective lesson plans. The next issue was specific to Group 1, and the last issue was specific to Group 2. In the following, we unpack each of these design issues.

[Insert Table 4 here]

4.2. Selecting a suitable history

A central design issue for both groups was the selection of the historical content that would best serve their respective instructional goals, although the time spent for settling a topic was different for the two groups (see Section 5). Group 1's priority was to select something that is 'accessible' and 'familiar' to students. The gas laws were expected to be a familiar topic that students would have already learnt from earlier grades. They reckoned that students would not be interested in the history of something that they do not know very much about. Similarly, Group 2 was keen to select content that is 'intriguing'. Rin recalled that she had to teach what she considered an uninteresting topic during her school internship the previous year, which was a challenge for her due to low student engagement. This was also related to their emphasis on the timeliness of the topic, as there was an ongoing debate about nuclear energy in Korea at the time of this study.

The prolificacy of the historical content was another common criterion. Group 1's focus was on selecting historical content that could illustrate many aspects of NOS. During the design conversation in Week 6, Sue said that since there are usually not that many opportunities for teaching NOS, it would be good to discuss a range of different aspects of NOS based on a single prolific historical episode. Group 2 wanted to select a topic that was ill-structured, open to interpretation, and able to elicit diverse reactions and reflections, which could fit with the debate format that they had agreed on. This approach enabled them to use HOS in a prolific and effective manner although the group's lesson only focused on the social NOS.

Other criteria for selection were also raised throughout the design process. For example, Group 1 had to consider the practicalities of including a historical experiment in the lesson such as the time constraint and the availability of apparatus; This practicality issue led Group 1 almost abandon the gas laws, but they wound up finding a way to circumvent the issue, which was to discard the experiment and instead focus on the analysis of data (see Section 5).

Overall, some PSTs still felt that their lack of knowledge of HOS limited their choice of topics for lesson planning, even after a semester-long course covering various periods of HOS. Sang's (from Group 2) comment in his end-of-term reflection exemplifies such a feeling:

> *The most challenging thing was to identify potential HOS content and select one. We did learn HOS throughout the semester, but an example to be used for a lesson had to be very concrete and adequate. We probably spent a couple of hours deciding what HOS content would fit what we wanted to teach. The limitation was that we as teachers*

did not know many interesting HOS contents. (Sang, interview)

4.3. Adapting history

Since both groups focused on specific case histories to design lessons, there were some issues around the pedagogical adaptation of 'real histories', which are complex and often contested, to serve the lesson goals effectively. Although the need for didactic adaptation and transposition always arises in translating the academic discipline into school subjects (Chevallard, 1989), the current study is unique in that it concerns the adaptation of HOS rather than scientific content. However, the issue of adaptation unfolded in distinct ways for the two groups: Group 1's issue was to *simplify* the details of the actual historical experiment, whereas Group 2's issue was to *fictionalise* the historical debates. First, Group 1 was keen to make the complicated actual historical experiment simpler for classroom implementation, as illustrated by the following conversation during the mid-term presentation:

> *Beom:* *Is there a particular reason you would give students experimental data?*
> *Instructor:* *Maybe because the experiment is too difficult?*
> *Myung:* *To see the deviation [from the prediction] the air pressure needs to be at least 20 atm, but we're not sure if a high school classroom can afford that. They need to change the temperature quite a lot so if it goes wrong and blow up … Students might think that scientific methods are only about observation and experiment, but we think data analysis is also part of science, so that's why we planned that for the lesson.*

As can be seen in Myung's response, Group 1's need for adaptation was focused on the practicality of replicating the historical experiment in the classroom setting with limited time and resources. The issue of adaptation was more explicit for Group 2. Rin thought that 'history cannot be objective' since it always involves interpretation, which made her believe that it is okay and even necessary to 'adapt' history by highlighting certain aspects and artefacts that are more relevant to the lesson goal. On the contrary, another group member, Sang, repeatedly expressed concerns about the risk of 'distorting' history as the group went through the filtering and selection processes. He recognised that if one tried to use the 'perfectly realistic history' in the lesson, 'what I want to tell students from the lesson [would] become less visible'.

Specifically, his concern was that ‘although it would be effective to emphasise the instructional intention, HOS would be distorted in that process’ (interview), so it was difficult for him to ‘find a line’ between these conflicting considerations. Regarding the role play about the Manhattan Project (**Figure 3**), Sang said:

> *We created imaginary characters to illustrate the tensions and stuff between science and politics. Also we sometimes said [in the instructional materials] that some characters had this thought, although they only were thinking that later on, but not at the time we were discussing it. (interview)*

With this concern in mind, Group 2 planned to state upfront in the lesson that the debate was fictional. The need for adaptation was not only to highlight instructional goals but also due to the lack of historical records about the Manhattan Project that were easily accessible. Regardless, both group’s adaptation issues arose as they started to look into the details of HOS and found out the complexity of the actual historical events. Common to the two groups was a realisation that HOS cannot be used in its original form but needs some form of adaptation to be used effectively in the lesson, a point that has been suggested in the literature on using HOS (Allchin, 1993; Rudge & Howe, 2009).

4.4. Teaching a topic with no correct answer

When using HOS to teach students about NOS, PSTs thought that NOS lacked a ‘correct answer’ and all PSTs from both groups referred to this characteristic of NOS as a source of challenge throughout the lesson planning process. By mid-semester, in both groups, some had already recognised that a HOS-based lesson would require a different instructional approach than a traditional science lesson due to the lack of definitive answers. Sue said that ‘NOS doesn’t have a clearly defined answer and there’s no boundary, so I thought we can’t teach students NOS by lecturing at all’ (interview). Myung realised that

> … conveying scientific theories and concepts to students and conveying NOS through HOS is different. I think that scientific theories and concepts are to some extent fixed, and the point is how we could deliver those ideas to students. But since NOS is not fixed, I think it’s more important to let students think more actively’.

He went on to say that what he had learnt from the science methods course was focused on 'delivering theories' whereas teaching NOS through HOS would need a separate set of instructional methods (written reflection). This was connected to what Myung said about assessment:

> When we give a science lesson, we check for what students have learnt through formative assessment. But if a student took our HOS lesson, I think it's a bit tricky to ask them to write an 'answer' for formative assessment. I'd rather ask them to 'write about your thoughts' and they would write. I think this would change the teaching approach completely. It's not about 'I will put this into their heads'. It's more about 'I will let them think about this a lot'. (interview)

Such lack of correct answers posed challenges to both groups, most notably regarding the teachers' role in orchestrating and controlling the discussion. Although both groups recognised that teacher-centred lectures would not be suitable for teaching with HOS, the two groups utilised different lesson formats (inquiry activity for Group 1 and debate activity for Group 2). From Group 1, Sue said "when teaching a topic without definitive answers … I'm not sure if the teacher is okay to intervene to lead the discussion according to the plan" (written reflection). From Group 2, Sang said that their lesson felt like a 'social studies lesson' where students debate, and the teachers synthesise the opinions to draw a conclusion, which was 'unfamiliar and difficult' for him. Relatedly, Group 2 chose to present the lesson goals not at the start of the lesson but at the end, which was a purposeful decision to prevent students 'thinking only that way and learning by rote'. Although this decision contradicted their knowledge of lesson planning that lesson goals need to be communicated upfront, they agreed that this way would be more effective.

4.5. Balancing science and history

Discussion about how much 'science' there should be in the lesson came up in Group 1. The group focused on a specific content topic within chemistry (i.e., gas laws), and although HOS guided their lesson planning process, the learning goals stated in their draft lesson plan were exclusively focused on content knowledge goals. Given that the assignment was to use HOS in a science lesson, the clash between HOS and science content in establishing the lesson focus was not surprising. In the mid-term meeting with instructors, a question was raised about how HOS was going to be used in their lesson, as their lesson foregrounded a scientific theory that was conceived in the past but is still accepted today. This issue was quite frequently discussed during the group's lesson planning. After some discussions, they figured out a way to justify their design, which is illustrated by Sue's comment:

> *When we were preparing the presentation, we thought talking about the changes of a [scientific] concept would count as HOS, but then started to ask if a simple enumeration of events could count as one. Having finished the presentation, now I think there are two different senses of HOS. The first is about different viewpoints about an event, and how different viewpoints were supported by different scholars to suggest what theories, and how they became accepted—which would be a narrow sense of HOS. On the contrary, we can call something HOS because scientific theories are presented in chronological order, which would be a broad sense of HOS. In that sense, I think our group's lesson was based on this broad sense of HOS. (written reflection)*

Sue's comment suggests that the group lesson planning experience helped her appreciate that there can be multiple approaches to incorporating HOS in science lessons. In other words, she realised that lessons could be using HOS without necessarily including HOS itself as a learning goal. Given that science teachers often struggle to find the alignment with between HOS and existing goals of subject knowledge (Höttecke & Silva, 2011), such a change in PSTs shows the potential of the lesson planning experience in developing PSTs' ideas about such alignment.

4.6. Empathising with people from the past

Empathy, or the act of imagining the thoughts and feelings of other people from one's own perspectives, is among the most important topics in history education research (Barton & Levstik, 2009). Historical empathy is often divided into two interrelated concepts, one focusing on 'perspective taking' and the other focusing on the notion of 'care' (Barton & Levstik, 2009). In our data, both senses of empathy were clearly voiced in Group 2's discussions. To highlight their learning goal of 'understanding that views of nuclear energy can be different across times and between individuals', it was deemed essential that students empathise with different stakeholders for the nuclear weapons from the early 20th century and those for the nuclear energy from the present. Rin was concerned whether ‘the students who are living the present would be able to take on different perspectives from different periods, as we intended’ (written reflection). Beom added that this would be particularly challenging for students who were asked to advocate the use of nuclear weapons. This need for empathy in Group 1’s lesson and the benefits of developing it was of interest to other group members too. Sue from Group 1 thought that ‘as long as the student understands their own role, it [the lesson] would help them think from another person’s perspective even when it’s not their opinion’ (interview). With these concerns, the group took particular care to fully immerse the learners in ‘what nuclear physics meant for different individuals in different social and cultural contexts’ (Beom, written reflection) before the debate began. The issue of empathy is more likely to occur when HOS is used to teach social, cultural and political aspects of science than epistemic aspects, which also relates to the fact that this issue did not emerge in Group 1 where the focus was the development of scientific knowledge.

4.7. Differences in the design processes across the two groups

Figures 4 and 5 illustrate what design issues arose for each group, from the start of the group work (Week 5) to the end. Based on the nature of the issues, they were classified into *content selection*, *sequence and organisation*, and *pedagogy*. For Group 1 (**Figure 4**), once they decided on the topic of the lesson (the gas laws) based on its potential to illustrate the progress of scientific theories, they discussed the organisation of the lesson in terms of what activities to include. To show the discrepancy between prediction and observation, a replication of historical experiments was first suggested, but it was soon called into question due to practical limitations. This brought the group back to selecting a more realistic topic other than the gas laws, which required advanced apparatus and experimental skills, but after a few iterations, they eventually returned to the gas laws but without the data collection by students. On the contrary, Group 2’s process was fairly linear, sorting out the content selection, sequencing and pedagogical matters successively (**Figure 5**). Once they decided on the lesson to focus on the sociocultural embeddedness of science, a couple of candidates from history of science were discussed, and once nuclear physics was selected, organisational and pedagogical matters were subsequently discussed and resolved.

As the figures suggest, although both groups started with a content selection issue and ended with a pedagogical issue, there is a significant difference in how the issues progressed between the three strands. In Group 1's discussion, the scientific content (the gas laws) was agreed upon first before the discussion moved to what aspect of NOS to highlight from the story. A practical problem with including the experiment made them revert to content selection and spend a long time considering an alternative scientific content area, before they finally found another way around the issue (doing data analysis rather than collection). In contrast, Group 2 first decided on the target NOS (sociocultural aspects of science) and then deliberated on matters such as choosing the most suitable case history to highlight, deciding the instructional model, whether to place the reflective discussion about NOS at the start or at the end, and what resources to provide for role play and group discussion. Although we do not intend to make causal claims between the topics the two groups selected and the linearity of their lesson planning process, the comparison does highlight how the initial priority setting within the team can influence the subsequent course of discussions. The comparison indicates that the main reason why Group 1 was stuck in content selection for a long time was the practical consideration that the required experimental conditions cannot be met in the classroom setting. This issue did not arise for Group 2, as no practical work was included in the lesson.

[Insert Figure 4 here]

[Insert Figure 5 here]

4.8. The influence of collaborative lsson planning experience on PSTs' views of using HOS in science lessons

The written reflection and interview data provided evidence of the impacts that the collaborative planning experience had on the PSTs, particularly as the design issues were recognised, deliberated and resolved. Some examples discussed in Section 4.4 through Section 4.6 suggest that the experience helped the PSTs broaden their views of HOS in science instruction and its potential values for high school students. Sue's comment about the broad and narrow senses of HOS indicates that she recognised different ways of incorporating HOS in science instruction to serve different goals. Similarly, there were several instances where PSTs noted the difference between teaching with and without HOS. For example, Myung's comment that a HOS lesson would require a different set of strategies than what he had learnt from the science methods course illustrates that he became aware of the limitations of his current knowledge when trying to use a new approach. Rin articulated that the collaborative planning process made her think different ways about education than what she had been used to, and said ‘science education could change its direction from simply teaching theories to providing comprehensive knowledge’ (interview). Finally, PSTs appreciated the value of teaching students about different perspectives and empathy, which they had not considered as relevant to their role as science teachers. **Sue** complimented Group 2’s role play activity since she thought it would help students think from another person’s perspective. In summary, the PSTs reported a range of benefits of the lesson planning experience in rethinking the purpose and methods of science instruction.

5. Discussion and recommendations

Using a multiple case study design and a deliberative approach to curriculum development, this study investigated how two triads of PSTs developed a science lesson focused on HOS, what design issues emerged, and what impacts the collaborative planning experience had on the PSTs. An examination of group discussion transcripts along with other data sources enabled a closer investigation into specific design issues that can be faced by novice science teachers when using HOS for science lessons. In the following, we discuss the implications in terms of HOS-based science instruction and collaborative curriculum design, and how the findings can inform and improve practice in teacher education.

Research has suggested that there are specific challenges for teachers who want to use HOS in their lessons (Henke & Höttecke, 2015; Höttecke & Silva, 2010). While these studies focused on experienced teachers, the current study looked at PSTs with little experience in lesson planning. Although the design issues identified in this study were in part suggested in previous studies, by employing the multiple, comparative case study design, we were able to cast light on some specific concerns and further nuances of these issues as manifested during the collaborative planning process over the semester. For example, the difficulty in finding and adapting teaching materials for HOS was both theoretically suggested (Allchin, 1993; Rudge & Howe, 2009) and empirically reported in previous studies (Henke & Höttecke, 2015), but our finding that the issue of adaptation can manifest in two ways—simplification by omitting historical details, and fictionalisation by inserting imaginary details—indicate that there is further complexities in using HOS for science instruction that need to be considered in supporting teachers. HOS can be used for various purposes (Matthews, 2014), and teachers can face different adaptation issues depending on whether HOS is focused on the procedural or sociocultural aspects of science and what pedagogical strategies are used (e.g., practical activity, demonstration, paper-and-pencil work, role play). This indicates that teacher educators should be aware of the different uses of HOS in science instruction and the specific support that novice teachers might need to plan lessons. Additional training and resources for teacher educators will ensure that teacher education programmes offer quality opportunities for preservice teachers to engage with HOS. Each of the design issues identified in this study merits further research on its own, which can benefit from theories in social studies and history education (Kötter & Hammann, 2017; Park & Cho, in press)—for instance, the issue of empathising with people from the past can be more systematically investigated through the lens of historical empathy (Brooks, 2009; Endacott, 2014). Such research will deepen our understanding of the factors that may facilitate or hinder the use of HOS in science education. Given that we focused on two groups of PSTs, future research can examine challenges arising from a broad range of lesson contexts to extend the insights from this study.

Based on the deliberative approach to curriculum development, we intentionally designed the lesson planning project as a group activity rather than an individual assignment. The benefits of collaborative lesson planning manifested in terms of teacher education practice and research. First, from the perspective of teacher education, the PSTs' reflections after the semester suggest that a collaborative planning experience can serve as a helpful opportunity for novice teachers to develop their knowledge of lesson planning (Voogt et al., 2015) with HOS. This suggests that future studies can utilise collaborative lesson planning projects for PSTs to develop their knowledge and skills in diverse non-traditional approaches to science learning, such as inquiry, NOS, and socioscientific issues. Second, from a research point of view, analysing collaborative design conversations provided a unique opportunity to closely investigate PSTs' challenges that might have been missed if the lessons were planned individually. As they work in groups, the design issues became evident and were deliberated amongst group members. Our analysis of the collaborative lesson planning as deliberation allowed for understanding the specific design issues, potential solutions, and how different concerns around lesson planning were negotiated between team members and resolved (Walker, 1971).

Ethics statement

Ethics approval for this study was granted by the Institutional Review Board of Seoul National University (Approval No. 1808/002-012).

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Table 1. Outline of course content and collected data

Weeks	**Course content**	**Data collected**
1–2	Introduction to HOS, NOS, and the 2015 national science curriculum of Korea	Survey
3–7	Approaches to HOS, ancient and medieval science, the scientific revolution, modern science	Design conversations (Week 5-)
8	Mid-term presentation of lesson plan	Written reflections, presentations, focus group interviews
9–13	Science in the 20th century, HOS in the East and Korea, Science-Technology-Society	Design conversations
14–15	Final presentation of lesson plan	Surveys, presentations, written reflections, individual interviews, developed lesson materials

Table 2. Self-reported participant backgrounds

Group	Name	Major	Year	School internship	HOS backgrounds
1	Myung	Chemistry	4	No	High interest. Read a few related books.
	Sue	Physics	2	No	High interest. Took an introductory philosophy of science course at the university and read a few related books.
	Gaeun	Biology	1	No	Fair interest. No prior engagement.
2	Rin	Chemistry	4	Yes	Low interest. No prior engagement.
	Beom	Physics	2	No	Low interest. No prior engagement.
	Sang	Physics	4	Yes	Fair interest. Took an introductory philosophy of science course at the university and read a few related books.
3 (Not included for analysis)	Chang	Physics	2	No	Fair interest. No prior engagement
	Hoon	Physics	2	No	Fair interest. Took an introductory philosophy of science course.

Table 3. Overview of developed lessons (summarised by authors)

	Group 1	**Group 2**
Lesson topic	The evolution of the gas laws	The Manhattan Project and nuclear energy
Instructional strategies	Experimental data interpretation, discussion	Historical role-play, debate
Target students	Grade 12	Grade 11
Learning goals	1. Explain from experimental data analysis that there are differences between the realistic and ideal gases 2. Explain the historical context related to Boyle, Charles and Avogadro 3. Understand NOS by comparing the result from data analysis and the theoretical prediction	1. Understand the history related to the development of nuclear weapon and nuclear energy 2. Understand that the benefits and risks of nuclear physics can vary depending on the time and personal beliefs 3. The values and uses of science are dependent on social and cultural context 4. Practice how to listen to diverse views in debates
Lesson outline [lesson materials used]	1. *Introduction*: The teacher stimulates students to recall the gas equation ($PV = nRT$) and introduces class activities. [slide show, textbook] 2. *Historical context*: The teacher explains the historical context for the gas laws found by Boyle, Charles and Avogadro. [slides, video clip] 3. *Experimental data analysis*: Each group of students are given the data for $P - V$ and $T - V$ relationships of H_2 and O_2 gases, find the equation and draw graphs. [slides, worksheet, graphing software] 4. *Discussion*: Each group discusses whether the analysis is consistent with $PV = nRT$ and speculates the possible reasons if inconsistency. [blackboard] 5. *Presentation and explanation*: Students present their speculations, their learning about what science is and what scientists do, etc. *6. Wrap-up and closing*	1. *Introduction*: The teacher briefly summarises the background of nuclear power from the 1900s to present. 2. *Historical role-play* [slides, role card, worksheet] a. The teacher explains the context (World War II) b. Students see the argument advanced by each character and choose one. c. Students engage in the role-play. d. Students reflect on the issues in the play and present. e. Students infer the social NOS from the play. 3. *Contemporary debate* [slide show, reading materials, worksheet] a. The teacher explains the new context (i.e., 2018) b. Students conduct the steps in 2b to 2e in one of these positions: NGO, scientists, government. 4. *Wrap-up and assessment*: Students share the outcome of the debate. The teacher reminds students that science is bound by sociocultural context. The teacher asks students whether some of the current science and technology will be received differently in the future. [slides, worksheet]

Table 4. Summary of design issues that emerged during lesson planning

	Group 1	**Group 2**
Selecting a suitable history	Accessible and familiar to students	Interesting to students Timeliness
Adapting history	Simplifying the details for practicality	Fictionalising the events for rich discussion
Teaching a topic with no correct answer	Interjecting to guide the discussion towards the intended conclusion	Moderating the discussion when there is no answer
Balancing science and history	Different ways of using HOS in science lessons	
Empathising with past people		Students' difficulties in understanding other people's perspectives

Figure 1. Analytical framework for design conversations

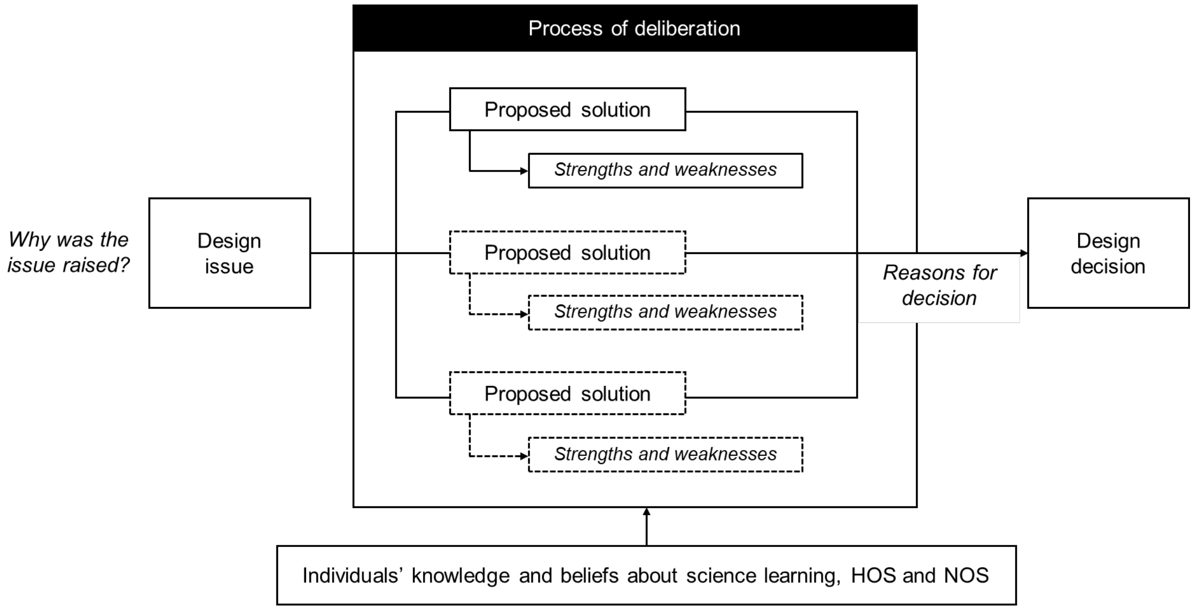


Figure 2. Original data from Boyle's experiment used in Group 1's lesson (Conant, 1957, p. 64)

A TABLE OF THE CONDENSATION OF THE AIR (Boyle's original data)

A	*B*	*C*	*D*	*E*
48	00		$29\frac{2}{16}$	$29\frac{2}{16}$
46	$01\frac{7}{16}$		$30\frac{9}{16}$	$30\frac{6}{16}$
44	$02\frac{13}{16}$		$31\frac{15}{16}$	$31\frac{12}{16}$
42	$04\frac{6}{16}$		$33\frac{8}{16}$	$33\frac{1}{7}$
40	$06\frac{3}{16}$		$35\frac{5}{16}$	35
38	$07\frac{14}{16}$		37	$36\frac{15}{19}$
36	$10\frac{2}{16}$		$39\frac{5}{16}$	$38\frac{7}{8}$
34	$12\frac{8}{16}$		$41\frac{10}{16}$	$41\frac{2}{17}$
32	$15\frac{1}{16}$	Added to $29\frac{1}{8}$ makes	$44\frac{3}{16}$	$43\frac{11}{16}$
30	$17\frac{15}{16}$		$47\frac{1}{16}$	$46\frac{3}{5}$
28	$21\frac{3}{16}$		$50\frac{5}{16}$	50
26	$25\frac{3}{16}$		$54\frac{5}{16}$	$53\frac{10}{13}$
24	$29\frac{11}{16}$		$58\frac{13}{16}$	$58\frac{2}{8}$
23	$32\frac{3}{16}$		$61\frac{5}{16}$	$60\frac{18}{23}$
22	$34\frac{15}{16}$		$64\frac{1}{16}$	$63\frac{6}{11}$
21	$37\frac{15}{16}$		$67\frac{1}{16}$	$66\frac{4}{7}$
20	$41\frac{9}{16}$		$70\frac{11}{16}$	70
19	45		$74\frac{2}{16}$	$73\frac{11}{19}$
18	$48\frac{12}{16}$		$77\frac{14}{16}$	$77\frac{2}{3}$
17	$53\frac{11}{16}$		$82\frac{12}{16}$	$82\frac{4}{17}$
16	$58\frac{2}{16}$		$87\frac{14}{16}$	$87\frac{3}{8}$
15	$63\frac{15}{16}$		$93\frac{1}{16}$	$93\frac{1}{5}$
14	$71\frac{5}{16}$		$100\frac{7}{16}$	$99\frac{6}{7}$
13	$78\frac{11}{16}$		$107\frac{13}{16}$	$107\frac{7}{13}$
12	$88\frac{7}{16}$		$117\frac{9}{16}$	$116\frac{4}{8}$

A. The number of equal spaces in the shorter leg, that contained the same parcel of air diversely extended.

B. The height of the mercurial cylinder in the longer leg, that compressed the air into those dimensions.

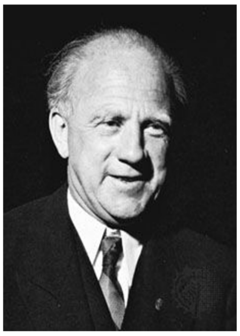
C. The height of the mercurial cylinder, that counterbalanced the pressure of the atmosphere.

D. The aggregate of the two last columns, *B* and *C*, exhibiting the pressure sustained by the included air.

E. What that pressure should be according to the hypothesis, that supposes the pressures and expansions to be in reciprocal proportion.

Figure 3. Group 2's role cards for the role play about nuclear weapons during World War II

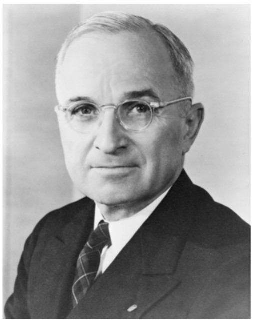
Werner Heisenberg



In the role play, Heisenberg explains the science of nuclear fission.

- A German scientist in charge of Germany's nuclear weapon project
- Nuclear fission: When a neutron is shot at uranium, uranium splits into barium, krypton and three nutrons.
- He was thought building nuclear bombs was possible. But he didn't think it would be before the end of World War II.
- Therefore, Germany focused on weapons other than nuclear weapons.

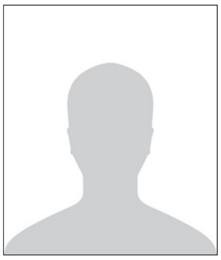
Harry Truman



In the role play, Truman represents President Roosevelt. He advocates the use of nuclear bombs and is in charge of deciding whether to use it or not.

- He thinks the war would end earlier if the US uses nuclear bombs to Japan. He wants to reduce the number of American soldiers killed at the war.
- At the end, he authorises the use of the nuclear bomb.

Secretary of Defence



In the role play, the Secretary of Defence convinces the president to use the nuclear bomb. Highly proud of his own country.

- He plans to use the nuclear bomb to Japan and end the war. It's already built, so it needs to be used.
- $2 billion was invested into the Manhattan Project. He thinks it would be a waste of money if the nuclear bomb is not used.
- He believes using the nuclear bomb will demonstrate the greatness of America to the world.

Figure 4. Group 1's lesson planning process over the semester

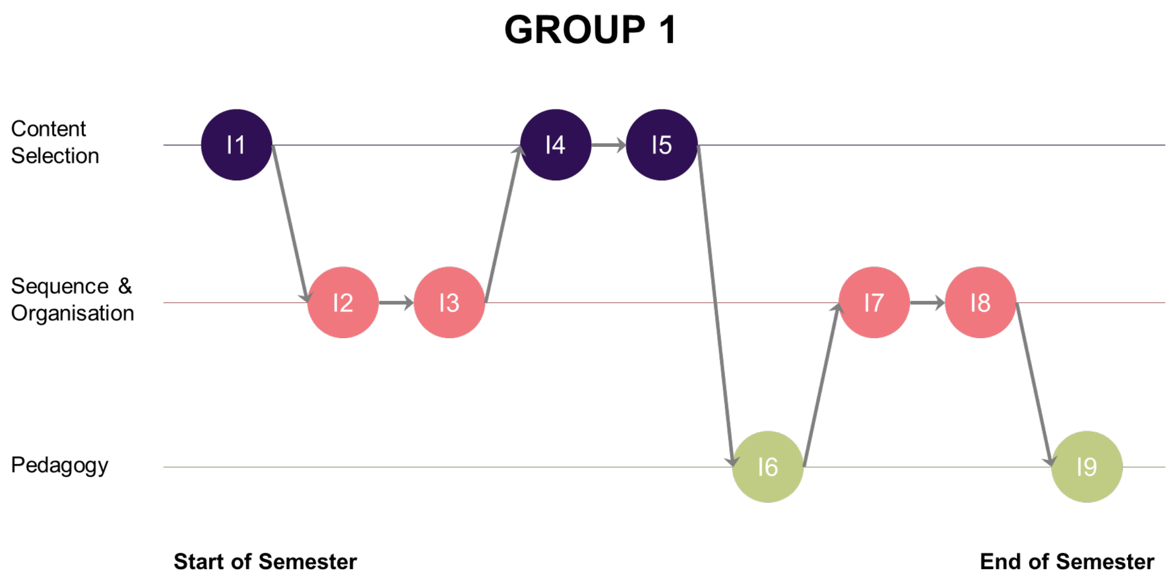


Figure 5. Group 2's lesson planning process over the semester