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ORIGINAL RESEARCH PAPER

Merging flipped classroom approaches with the 5E inquiry model: a design heuristic

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ABSTRACT

Most often, flipped classroom approaches in science and mathematics classrooms follow a traditional approach to teaching, where students receive direct instruction as homework and have to apply and deepen their knowledge in a follow-up lesson. Little is known about the arrangements of in-class and out-of-class phases fostering learning through inquiry in flipped classroom scenarios. To support teachers' lesson planning practices, we developed a design heuristic for flipped classroom scenarios based on the 5E inquiry model. We implemented this design heuristic in an online professional development course for secondary mathematics teachers and collected 18 lesson plans. To explore how participating teachers adopted the design heuristic in their lesson plans, we conducted a document analysis on our data. We identified the following three major categories: (a) pre out-of-class phases to engage students, (b) in-class phases for student-centred learning activities and (c) post out-of-class phases for consolidation. Furthermore, we analysed lesson plans with the 5E model scoring instrument. Findings indicate that teachers' lesson plans were mainly in line with the 5E model, but most participants struggled with selecting appropriate assessment techniques. Based on the analysis, this paper discusses revision decisions regarding the proposed design heuristic.

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1. Introduction

In traditional flipped classroom scenarios, learners are required to watch videos or read text material before class as homework, and student-centred learning activities are applied in-class (e.g. Love et al., 2014). Flipped classroom approaches have shown good potentials to increase student achievement in mathematics (Charles-Ogan & Williams, 2015; Esperanza et al., 2016), with some studies indicating students' preferences for learning mathematics in a flipped classroom in comparison to more traditional approaches to teaching (e.g. Muir, 2016).

Borko and Putnam (1996) recognized that learners construct knowledge based on their prior knowledge. Concerning flipped classroom approaches, this finding suggests that teachers should design flipped classroom scenarios stimulating learners to extend or revise

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their prior knowledge because learners do not simply interiorize the information provided as homework prior to class. Rather than merely presenting facts or worked-out examples, learning processes in flipped classroom scenarios can also be initiated by posing inspiring questions or problems. Even though learning through inquiry is especially crucial for the development of higher-order thinking skills (Krathwohl, 2002), ways to foster inquiry-based learning in flipped classroom scenarios have rarely been addressed in science and mathematics education research.

Herreid and Schiller (2013) surveyed science, technology, engineering and mathematics teachers regarding their use of flipped classroom approaches. Teachers reported that due to flipping their classes, they gained more time for student-centred learning activities, where learners were more actively involved in the learning process. Combining learning through inquiry with flipped classroom approaches could lead to freed up in-class time which subsequently could be used for exploration (Love et al., 2015). Recent mathematics education research (Voigt et al., 2020) investigated uses of different types of videos such as introductory, inquisitive and illustrative videos in flipped classrooms. Teachers need to plan on how to use different types of videos and the arrangement of in-class and out-of-class phases in flipped sequences. However, designing lesson plans for flipped inquiry scenarios can be challenging for educators, and research on teachers' lesson planning practices for flipped classroom scenarios in science and mathematics education is lacking.

To address the gap mentioned above, we are developing a design heuristic aimed at supporting teachers' lesson planning practices for inquiry-based flipped classroom scenarios. In the design heuristic, we merge flipped classroom approaches (Abeysekera & Dawson, 2015) with the widely used 5E (Engage, Explore, Explain, Elaborate, Evaluate) inquiry model (Bybee, 2009). We refer to this combination as the 5E-based flipped classroom. For the development of the design heuristic we are conducting a design-based research study (Wang & Hannafin, 2005). The first author leads this ongoing design-based research study in consultation with the other two authors. Since this design-based research study is ongoing, theory development is not yet complete and will not be presented in this paper. In the current paper, we present the results of the first design-based research cycle. The following two research questions guided the research presented in this paper:

(1) How do secondary mathematics teachers adopt the presented design heuristic regarding the use and arrangement of in-class and out-of-class phases in flipped classroom scenarios in their lesson plans?
(2) To what extent does the presented design heuristic support secondary mathematics teachers in developing flipped classroom lesson plans that are in line with the 5E inquiry model?

In the following, we begin by taking a closer look at the relevant literature regarding flipped classroom approaches and inquiry-based learning which form the theoretical background of our study. We then present the design heuristic implemented in the first design-based research cycle. Next, we explain how we arrived at identifying three main categories among the 18 lesson plans and how we applied the 5E model scoring instrument (Goldston et al., 2013) for evaluation. Subsequently, we provide the results of our analysis of teachers' lesson plans as well as the discussion. Finally, we draw conclusions and plans for further developing the design heuristic.

As a note, in this paper, the term 'participating teachers' refers to those teachers who uploaded the lesson plans during the online professional development course described in this study. The term 'students' represents learners between the age of 10–19 years in the context of our study as we are focusing on secondary mathematics education in Austria in our study.

2. Theoretical background

2.1. Flipped classroom approaches

Teachers commonly apply flipped classroom approaches by assigning educational material such as videos containing direct instruction before class and students are asked to participate actively in learning activities during class (Wasserman et al., 2015). Still, there is no universal definition of a flipped classroom (Wolff & Chan, 2016). A closer examination of various definitions of flipped classroom approaches suggests information transmission does not necessarily have to precede class. For instance, according to Lage et al. (2000), flipped classroom is defined as ' . . . events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa' (p. 32). Wolff and Chan (2016), on the other hand, state flipped classroom is 'any teaching model which replaces in-class lecture modules with video or audio lectures to use the freed in-class time for interactivity' (p. 13). This definition implies a learning process in a flipped classroom scenario can also be started by letting learners first explore a phenomenon in-class and later consolidate their findings through information transmission out-of-class.

In this paper, the term flipped classroom means that information transmission teaching is primarily done out-of-class, freed in-class time is used for student-centred learning activities, and learners need to complete both pre- and post-class activities to fully benefit from in-class work (Abeysekera & Dawson, 2015). As a note, Abeysekera and Dawson (2015) identified the characteristics of a flipped classroom within tertiary education settings, but they can also be transferred to and applied at the secondary level.

2.2. The 5E model and essential features of classroom inquiry

The 5E model (Bybee, 2009) consists of 5 phases which all begin with the letter 'e': engage, explore, explain, elaborate and evaluate (see Figure 1).

The use of the 5E model for open, guided or direct inquiry depends on the teachers' choice: whether learners ask the questions to be investigated, choose among proposed questions, or teachers provide the questions. We developed our design heuristic based on the 5E model because the five essential features of classroom inquiry, including (i) *the learner's engagement in scientifically oriented questions*, (ii) *priority of evidence in response to questions*, (iii) *formulation of explanations from evidence*, (iv) *explanations connected to scientific knowledge* and (v) *communication and justification of explanations* (National Research Council, 2000, p. 29), can be implemented through 5E lessons as outlined in the following paragraph.

According to the 5E model (Bybee, 2009), a learning cycle starts with engagement during which teachers could show a problematic situation, define a problem or develop questions under investigation together with the learners. Hence, the first essential feature

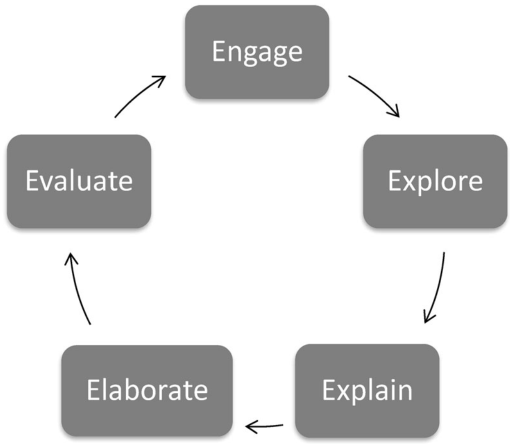


Figure 1. The 5E inquiry model

of classroom inquiry (National Research Council, 2000) where *learners engage in a scientifically oriented question* is included in the first phase. Activities of the first phase should motivate students and connections to prior experiences should be drawn. During the phase of exploration, teachers support students' exploration process. Two essential features of inquiry, namely, *students give priority to evidence in responding to questions* and *students formulate explanations from evidence*, can be found in the exploration phase. Next, at the stage of explanation, learners should articulate their findings, supported by their teachers, who might help learners to find appropriate terms or concepts. Two further essential inquiry features which involve *students trying to link their explanation to scientific knowledge* as well as *communicate and justify explanations* could be addressed in the explanation phase. The elaboration phase aims to involve students in additional activities facilitating the transfer to closely related but new situations to generalize concepts, processes or skills. By applying what students have learned during elaboration, students might *give priority to evidence in response to questions* and *formulate explanations from evidence*. Finally, at the stage of evaluation, learners can evaluate their understanding by using their acquired skills whereby the essential inquiry feature *students communicate and justify explanations* could occur again.

2.3. Inquiry-based learning and flipped classroom approaches

Further initial developments and modifications of flipped classroom approaches to enable learning through inquiry in flipped scenarios were made, for example, by Song and Kapur (2017). They combined the pedagogy of productive failure (Kapur, 2010) with flipped classroom and called this approach *productive failure-based flipped classroom*. To measure the effectiveness of the two pedagogical designs, they conducted a quasi-experimental study where they compared two secondary school mathematics groups. One group was taught according to the traditional flipped classroom concept and another according to the productive failure-based flipped classroom. In the productive failure-based flipped classroom, the students tried to solve problems concerning the new concepts to be learned during class, even if they encountered failures, followed by consolidating the concepts by watching video clips at home. In the traditional flipped classroom, learners first had to watch these videos as homework. Afterwards, students practised in the classroom. The results indicated both groups showed a significant improvement in procedural knowledge. In terms of conceptual knowledge, the group which was taught according to the productive failure-based flipped classroom scored better than the traditionally flipped group. These results suggest the position of direct instruction in the pedagogical design of a flipped classroom matters and the productive failure-based flipped classroom could be more effective in promoting the learners' problem-solving skills.

Similar to the 5E model (Bybee, 2009), Song and Kapur (2017) included a phase of engagement, exploration and explanation in their scenario of a productive-failure-based flipped classroom. However, an elaboration phase where students should apply their acquired skills to new situations as well as an evaluation phase are missing. In a 5E-based flipped classroom scenario, the whole inquiry cycle with all five phases should be covered. Therefore, the 5E-based flipped classroom we are describing in this paper can be seen as a further development of the productive failure-based flipped classroom approach.

2.4. Design heuristic for 5E-based flipped classroom scenarios

To assist teachers in creating lesson plans for inquiry-based flipped classroom scenarios, we are developing a design heuristic based on the 5E inquiry model (Bybee, 2009). For each phase of the 5E model, the design heuristic (see Table 1) contains descriptions of pos-

Table 1. Design heuristic for 5E-based flipped classroom scenarios.

5E phase	Out-of-class activities	In-class activities
1. Engagement	Teacher introduces the educational scenario to provoke curiosity and aims to activate prior knowledge using digital material (e.g. interactive video with integrated questions) when appropriate. Students go through the provided material at their own pace and note any questions that arise.	Teacher leads classroom discussion, and the question(s) for investigation is/are developed. Students engage in the classroom discussion.
2. Exploration	Teacher provides a learning environment to be explored. Students prepare for class by inspecting the learning environment presented.	Teacher supports the exploration process and encourages learners to formulate findings based on their experiences. Students explore the learning environment and share their findings with the class.
3. Explanation	Teacher introduces relevant concepts or theories that might have escaped students' notice or that students are not familiar with to foster deeper understanding, e.g. using video, textbook materials. Students study the provided material and compare it with their explanations.	Teacher and students utilize the concept(s) and the experience(s) to describe and explain the phenomenon and answer the initial question(s).
4. Elaboration	Teacher describes new, but closely related problems, e.g. using video and/or textbook materials. Students get the task to identify new but closely related situations.	Teacher promotes elaboration. Students apply the knowledge gained to solve new, but closely related problems.
5. Evaluation	Teacher provides self-assessment for learners. Students engage in self-assessment tasks to reflect on their learning process.	Teacher applies an assessment technique to evaluate students' progress towards achieving educational goals.

sible activities during class (in-class activities) as well as outside the physical classroom as homework (out-of-class activities). Following Abeysekera and Dawson's (2015) definition of a flipped classroom, opportunities for student-centred activities were implemented during class and activities which contain primarily direct instruction as homework. Examples of digital educational materials have been included in the design heuristic but should only be used if they promote students' learning process. The proposed design heuristic should act as a rough blueprint for teachers when developing lesson plans for 5E-based flipped classroom scenarios. Therefore, teachers can adapt the design heuristic in a flexible way to their teaching needs and are not forced to incorporate an in-class as well as a homework phase in each 5E phase.

3. Methodology

3.1. Context and participants

Twenty-two secondary mathematics teachers voluntarily participated in a three-week long online professional development course which was offered at the University College of Virtual Teacher Education in Austria. The participating teachers are teaching students between the age of 10–19 years in different types of secondary schools. In Austria, teacher training for flipped classroom approaches is gaining popularity. In most of these professional development courses teachers only get to know traditional flipped classroom approaches, where direct instruction is implemented before class; other ways of flipping a class are rarely addressed. Therefore, the topic of our course was the use of the 5E-based flipped classroom approach in secondary mathematics education, and it was set up by the first author on the learning management system Moodle. We decided to implement the design heuristic in an online course because of the easy exchange of information and the possibilities for teachers to participate irrespective of time and place (Vrasidas & Zembylas, 2004). Out of the 22 participating teachers 18 teachers finished the online course. Four teachers did not upload a lesson plan and complete the online course due to illness or limited time resources. Participants gave informed consent to the use of their lesson plan for research purposes. Still, we did not ask them to provide their demographic information as it did not appear to be essential for our study.

3.2. Procedure of the online professional development course

At the beginning of the online course, the participants were not familiar with the design heuristic. According to Tuan et al. (2017), videos and inspiring lesson plan examples provided on a website are two of the main factors that influence science and mathematics teachers' inquiry-based teaching conceptions in a professional development course on assisted inquiry-based teaching. Hence, we decided to incorporate both, videos explaining relevant concepts and lesson plan examples, throughout the course. Weinhandl and Lavicza (2018) investigated central aspects when introducing mathematics teachers to flipped classroom approaches in Austria. As one of these aspects, Weinhandl and Lavicza (2018) stated that at the end of such a professional development course teachers should have created a product which reflects their learning process. In our case, these learning products are the developed lesson plans. Their results also suggest the course design should enable cooperative learning among a group of teachers (Weinhandl & Lavicza, 2018). To facilitate cooperative learning, our online course was moderated by the first author who is also an experienced online tutor.

Several steps were taken to make the teachers familiar with the design heuristic and have them use the design heuristic for lesson planning. In the first three course steps, teachers were introduced to the 5E inquiry model, flipped classroom approaches and our design heuristic using videos, articles and different activities. Next, in the fourth course step, six lesson plan examples made by the first author using the design heuristic were presented. Based on provided guiding questions, teachers were asked to discuss the six lesson plan examples in online forums. Subsequently, in a fifth course step, participants developed their own lesson plan on a self-selected topic using the design heuristic. Finally, in a sixth and last course step, participants received feedback on their lesson plans from their colleagues and the online tutor.

In the current study, we are focusing on the lesson plans developed in the fifth step of the online course. During the design phase of the lesson plans, no support was provided by the online tutor; participants were asked to only use the design heuristic for lesson planning. In their lesson plans, teachers were asked to state clear and appropriate lesson objectives for their lesson plans. By appropriate, we mean the lesson objectives should align with the teachers' respective school curriculum. The lesson plans were required to contain a detailed description of the planned out-of-class as well as in-class activities for each 5E phase and a complete materials list.

3.3. Analysis

The 18 collected lesson plans were coded and analysed using elements of a qualitative content analysis approach (Schreier, 2012) within a document analysis (Bowen, 2009) to explore how teachers applied the design heuristic in their lesson plans. Furthermore, the 5E lesson plan scoring instrument (Goldston et al., 2013) was utilized to examine the extent to which the design heuristic supported the participating educators in developing lesson plans in line with the 5E inquiry model. In the following, we describe how we conducted a document analysis and applied the 5E lesson plan scoring instrument.

3.3.1. Document analysis

To identify didactical patterns regarding the use and arrangement of in-class and out-of-class phases among the lesson plans, we conducted a document analysis (Bowen, 2009) of the 18 collected lesson plans. We opted to analyse written lesson plans because the inclusion of detailed descriptions, references and materials makes them fruitful for our study. Moreover, as written text was our main source of data, interaction effects between participants and researchers should not occur (Kondracki et al., 2002). For analysing the lesson plans, we followed coding procedures related to a qualitative content analysis approach (Schreier, 2012). In particular, we used elements of a combined deductive-inductive approach to content analysis (Schreier, 2014). By combined deductive-inductive, we mean we first created a preliminary coding list based on the design heuristic, containing an in-class and an out-of-class category for each 5E phase. As the coding process proceeded, we modified and refined the initial coding list by adding new codes and revising categories until they were mutually exclusive (Miles & Huberman, 1994). We focused on semantic (closer to participants' language) and latent (information is given indirectly) elements of the data. Examples of semantic codes included: 'teacher answers questions during engagement', 'use video as homework in the explain phase', and 'students tackle similar situations'; examples of latent codes included 'activation of prior knowledge' and 'outsourced information transmission for consolidation'.

3.3.2. 5E lesson plan scoring instrument

Goldston et al. (2013) developed the 5E lesson plan scoring instrument for inquiry-based teaching (hereafter referred to as 5E ILPv2 which stands for the 5E inquiry lesson plan scoring instrument version 2) using a psychometric approach. The 5E ILPv2 was verified with 224 pre-service science teachers. Factor analysis confirmed the five factors of the instrument which include engage (0.94), explore (0.99), explain (0.96), elaborate (0.97) and evaluate (0.95). With a total instrument reliability estimate of 0.98, the 5E ILPv2 is a solid instrument for assessing written 5E lesson plans.

The 5E ILPv2 includes four items for the engage phase, four items for the explore phase, six items for the explain phase, three items for the elaborate phase and four items for the evaluation phase. Moreover, the 5E ILPv2 employs a 5-point Likert scale which ranges from 0 to 4 points per item and employs five scoring criteria as follows: unacceptable (score 0), poor (score 1), average (score 2), good (score 3) and excellent (score 4).

On the one hand, the 5E IPLv2 can be used to measure an individual's ability to set up a 5E lesson plan. On the other hand, the instrument is intended to assist teacher educators in revising their strategies regarding teaching how to design 5E lesson plans. We used the 5E IPLv2 to detect strengths as well as weaknesses of the proposed design heuristic regarding the 5E model. To establish reliability, the first author as well as another experienced teacher educator rated the 18 lesson plans according to the items and scoring criteria from the 5E ILPv2. The other teacher educator was, apart from using the 5E ILPv2 for analysis, not involved in this study. First, the two teacher educators familiarized themselves with the scoring instrument by reading the detailed explanation for each scoring criterion of the 5E ILPv2 and scored all lesson plans individually. Afterwards, scores were compared and discussed until consensus on the analysis was reached. Due to the small sample size, we decided to cluster the scoring criteria together into 'fulfilled item' and 'failed item' rather than using descriptive statistics to present the results. A lesson plan fulfilled the item if it got a score from 2 to 4 ('average' to 'excellent'). If the lesson plan received a score lower than 2 ('unacceptable' or 'poor'), it failed the criterion.

4. Findings and discussion

Following the two research questions presented in the introduction, the results will be presented and discussed according to each research question. The first sub-section *Identifying didactical patterns among the lesson plans* is related to the first research question and the second sub-section *Evaluation of the lesson plans using a 5E scoring instrument* is associated with the second research question.

4.1. Identifying didactical patterns among the lesson plans

Conducting a document analysis, we generated three major categories regarding the application of the 5E-based flipped classroom design heuristic in teachers' lesson plans: (a) pre out-of-class phases to engage students, (b) in-class phases for student-centred learning activities, and (c) post out-of-class phases for consolidation. The last two categories were the most predominant and the first category less common but still strongly represented in the data set. Below the three categories as well as the underpinning ideas and concepts will be described in more detail. Additionally, a lesson plan example addressing all three major categories will be presented after the descriptions of the categories.

4.1.1. Pre out-of-class phases to engage students

The first category was built upon repeated embedding of pre out-of-class phases in the engage and elaborate phases. The word 'engage' in the title of the category does not only refer to the 5E phase engage; it should also include the intention to engage students in the 5E elaboration phase in a pre-class phase. Moreover, some teachers planned to provide self-assessment activities in a pre out-of-class phase to prepare learners for the evaluation phase.

To differentiate the pre-lesson phases meant in this category from the ones used in traditional flipped classroom scenarios, we will contrast two lesson plan examples. Following the 5E-based flipped classroom approach, in one lesson plan prior knowledge regarding the right circular cone was activated with online resources in a pre-lesson phase (see Table 2). Based on this pre out-of-class phase, students were asked to derive the formula for the total surface area of a right circular cone themselves with the help of a dynamic geometry environment. In contrast, in another lesson plan, a teacher planned to present the derivation of the Laws of Sines and Cosines prior to class with a video. According to this lesson plan, learners should comprehend the derivation of the Laws of Sines and Cosines at home using the video and apply their gained knowledge in a follow-up lesson. This lesson plan followed a traditional approach to flipping a class because the new concepts were introduced straight away at the beginning of the learning process in a pre-class phase.

The pre out-of-class phases described in this category elicit what students already know. Hence, we assume the core idea underlying the first category is that learning could be interpreted as reorganizing and expanding existing knowledge. Because of the learners' mental engagement, the central idea of the first category may be related to what has already been shown in brain-based research (Jensen, 2008).

4.1.2. In-class phases for student-centred learning activities

The second category captures the way of using the gained in-class time in a flipped classroom for student-centred learning activities. In contrast to lecture-based teaching approaches, in inquiry-based flipped classroom scenarios learners are at the heart of education. In the collected lesson plans, information transmission was mainly outsourced to homework phases, which is captured by the other two categories. To illustrate the second category, we will summarize some examples from the data. Participating teachers envisioned using the freed-up in-class time for encouraging learners to raise questions for investigation or develop such questions together. Apart from a few exceptions, teachers intended to let students explore new concepts during the lesson and give them enough time to formulate their findings. Moreover, planned whole class discussions were mainly based on students' explanations. Finally, most lesson plans included hands-on activities where learners should apply their acquired concept knowledge and skills to new situations during the elaborate phase.

As the 5E model is grounded in constructivist learning theories such as Dewey's reflective thinking (1938), it seems like the core concept which underpins this category aligns with constructivism. According to constructivist learning theories, learners construct their knowledge through active participation and are not seen as passive receivers of facts and concepts. To be even more specific, social constructivism (Vygotsky, 1978) plays a distinctive role, because knowledge might be constructed among a group of learners during class in inquiry-based flipped classroom scenarios supported by teachers. The role of a teacher in flipped classroom scenarios is that of a facilitator or coach rather than being merely a knowledge provider (Hwang et al., 2015), which is also the case in 5E lessons.

4.1.3. Post out-of-class phases for consolidation

This category suggests another way of implementing a homework assignment. Unlike the first category, the third category suggests integrating an out-of-class phase after class. The following ideas are underpinning the third category.

For introducing a new topic in flipped classroom scenarios, educators do not always have to implement direct instruction preceding class. Learners should be given the opportunity to feel the need for an introduction or at least appreciate the advantage when the teacher explains it. This principle was originated by Branford (1908) and also applies for flipped classroom teaching, where consistently using information transmission at the beginning of the learning process should be avoided. To the extent possible, learners should first make their own experiences before educators explain concepts. In such a flipped classroom setting mistakes are seen as opportunities. Hence, this type of flipping a classroom could be referred to as a productive failure-based flipped classroom approach, where learners first tackle different problems during class and afterwards should consolidate their findings at home (Song & Kapur, 2017).

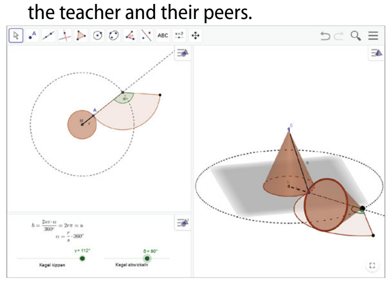
Concerning the consolidation at home, in the collected lesson plans, most educators intended to present students with videos including complete explanations or just written worked-out examples as a homework assignment in the phase of explanation or elaboration. To ensure watching a video was an active process, most teachers included YouTube videos with integrated quiz assignments. The duration of the YouTube videos participating teachers implemented in their lesson plans ranged from one minute to six minutes. According to Bybee et al. (2006), educators in 5E lessons commonly use various strategies and techniques to develop student explanations, including videos. In 5E based flipped classroom scenarios, teachers can use a video or other educational material in a homework phase during the stage of explanation to present concepts or processes which may have escaped students. Sweller and Cooper (1985) found that learning from worked-out examples can be useful. By presenting such examples in a video, a step-by-step solution with verbal explanations can be provided. Because of this added auditive component, students do not need to explain intermediate solution steps to themselves. This type of video can be referred to as an illustrative video (Voigt et al., 2020).

4.1.4. Lesson plan example

To illustrate the findings of the document analysis, Table 2 presents a representative lesson plan example of the collected lesson plans. The topic of this lesson plan example is the derivation of the formula for the total surface area of a right circular cone. We have chosen to present this lesson plan example because all three major categories are addressed. Due to illustrative reasons, we summarized the descriptions of the lesson plan and translated the lesson plan from German to English. Apart from the dynamic GeoGebra activity, we did not include the implemented materials of the lesson plan as they are only available in German and are not that essential for our study.

In the lesson plan shown in Table 2, the first major category *pre out-of-class phases to engage students* is addressed at the beginning of the sequence by activating students' prior knowledge preceding class. However, in the phase of elaboration, students are not engaged in the tasks out-of-class. A reason might be that in this lesson plan parts of the explanation and elaboration are tackled in the same lesson during class and to insert a homework assignment between these two phases would only cost unnecessary time. In most other

Table 2. Lesson plan example 'Formula for the total surface area of a right circular cone'.

5E phase	Out-of-class activities	In-class activities
Engagement	Prior knowledge regarding the right circular cone is activated with online resources (website with online activities).	Teacher answers questions from the homework phase within a classroom discussion. Teacher presents the educational scenario where students should derive the formula for the total surface area of a right circular cone.
Exploration	Nil	Students explore the following GeoGebra dynamic activity themselves supported by the teacher and their peers.  Students share their experiences and start formulating and justifying their findings and explanations in groups.
Explanation	Students are asked to watch a YouTube video (duration: 2:27) explaining how to derive the formula for the total surface area of a right circular cone. Students should compare their derivation with the one presented in the video and note any questions that arise.	Teacher answers questions from the homework phase within a classroom discussion.
Elaboration	Nil	Students should apply their gained knowledge by solving several textbook examples calculating the total surface area of right circular cones in pairs.
Evaluation	For self-assessment, students calculate the total surface area of right circular cones with self-chosen values and check their results with an online cone calculator.	Nil

lesson plans, participating teachers did not plan to assign homework in each phase of the 5E model just for the sake of the proposed design heuristic.

According to flipped classroom approaches (Abeysekera & Dawson, 2015), information transmission is mostly outsourced in the presented lesson plan example in Table 2. Only the presentation of the educational scenario to be investigated is implemented in the engagement phase during class and leads to exploratory activities in-class. In this lesson plan example, a dynamic GeoGebra activity was planned to be used for exploration (see Table 2). It should be noted that GeoGebra (Hohenwarter et al., 2009) is the most widely used dynamic mathematics software in Austria. Prior research (Erbas & Yenmez, 2011) has shown that combining student-centred inquiry approaches with dynamic geometry environments, such as GeoGebra, can enhance students' conjecturing skills and improve student performance.

In this lesson plan example, there is a logical transition from the exploration to the explanation phase because, after exploration, students should start formulating and justifying their explanations in groups. As part of the explanation phase, a *post out-of-class phase for consolidation* is implemented, where the third major category can be determined. For consolidation, a YouTube video was planned to be used. This YouTube video is a type of illustrative video (Voigt et al., 2020) as the derivation of the formula for the total surface of a right circular cone is explained and illustrated.

The second major category *in-class phases for student-centred learning activities* can be mainly found in the exploration and elaboration phase in this lesson plan example, where hands-on activities have been implemented. During elaboration, students are asked to solve several textbook examples calculating the total surface area of right circular cones in pairs.

In the evaluation phase, just a self-assessment activity was planned to be used in this lesson plan which is one of the weak points of this example and will be further discussed in the following section.

4.2. Evaluation of the lesson plans using a 5E scoring instrument

Table 3 shows the results of the lesson plan analysis following the 5E ILPv2 (Goldston et al., 2013). In general, the results show the 18 collected lesson plans were mostly in line with four phases of the 5E inquiry model, namely the engagement, exploration, explanation and elaboration. However, the items regarding the evaluation phase have not been addressed adequately.

Engage item 1 refers to the activation of learners' prior knowledge. The majority of participating teachers intended to use homework assignments before class in the engage phase to elicit students' prior knowledge; this has also been described in the category *pre out-of-class phases to engage students* developed via document analysis. However, eight lesson plans failed engage item 1. To tackle this result, we will change the design heuristic so the engagement out-of-class phase will mainly focus on eliciting prior knowledge. The other three items of the engagement phase were passed by over three-quarters of the lesson plans.

Table 3 shows that almost all participants attempted to address the first three items from the phase of exploration satisfactorily in their lesson plans. For instance, learning activities implemented in the phase of exploration were student-centred and hands-on, which is also characteristic of in-class activities in flipped classroom approaches (Long et al.,

Table 3. Evaluation of lesson plans according to the 5E scoring instrument.

5E ILPv2 item	Item description	Number of lesson plans that fulfilled the criterion ($N = 18$)
Engage item 1	The engage phase elicits students' prior knowledge (based upon the objectives).	10
Engage item 2	The engage phase raises student interest/motivation to learn.	17
Engage item 3	The engage phase provides opportunities for student discussion/questions (or invites student questions).	14
Engage item 4	The engage phase leads to the exploration phase.	15
Explore item 1	During the exploration phase, teachers present instructions.	16
Explore item 2	Learning activities in the exploration phase involve hands-on/minds-on activities.	17
Explore item 3	Learning activities in the exploration phase are student-centred.	17
Explore item 4	The inquiry activities of the exploration phase show evidence of student learning (formative authentic assessment).	10
Explain item 1	There is a logical transition from the exploration phase to the explanation phase.	16
Explain item 2	The explanation phase includes teacher questions that lead to the development of concepts and skills.	16
Explain item 3	The explanation phase includes mixed divergent and convergent questions for interactive discussion facilitated by teacher and/or students to develop concepts or skills.	14
Explain item 4	The explanation phase includes a complete explanation of the concept (s) and/or skill (s) taught.	16
Explain item 5	The explanation phase provides a variety of approaches to explain and illustrate concept or skill.	14
Explain item 6	The discussions or activity during the explanation phase allows the teacher to assess students' present understanding of concept(s) or skill(s).	15
Elaborate item 1	There is a logical transition from the explanation phase to the elaboration phase.	12
Elaborate item 2	The elaboration activities provide students with the opportunity to apply the newly acquired concepts and skills into new areas.	17
Elaborate item 3	The elaboration activities encourage students to find real-life connections with the newly acquired concepts or skills.	10
Evaluation item 1	The lesson includes summative evaluation, which can consist of a variety of forms and approaches.	8
Evaluation item 2	The evaluation matches the objectives.	7
Evaluation item 3	The evaluation criteria are clear and appropriate.	6
Evaluation item 4	The evaluation criteria are measurable (i.e. using rubrics).	6

2017). However, only ten out of eighteen lesson plans passed explore item four, which is about assessing students' learning during inquiry with a formative assessment approach. We assume participants focused on assessing students' learning in the phase of explanation (see Table 3, explain item 6) rather than during exploration. According to Bybee (2009), informal evaluation can be implemented throughout the whole 5E learning cycle. During inquiry activities, teachers could use informal assessment conversations to probe students' thinking (Shavelson et al., 2008) and offer students valuable real-time feedback (Ruiz-Primo & Furtak, 2007). We will include examples for informal evaluation, such as informal assessment conversations, in the in-class phase of the exploration in the revised version of the design heuristic.

As shown in Table 3, nearly all lesson plans addressed the six items regarding the phase of explanation. One of the reasons is that almost all teachers intended to include a complete explanation of the concepts or skills to be acquired in a post out-of-class phase. This result seems to be in accordance with the category *post out-of-class phases for consolidation,* which was generated in the course of this study through document analysis.

In two-thirds of the lesson plans, a logical transition from the phase of explanation to the elaboration phase could be determined (see Table 3, elaborate item 1). Goldston et al. (2013) included elaborate item 1 and explain item 1 to ensure the connection between the different 5E phases. Although teachers intended to expose learners to new situations in the elaborate phase, in eight lesson plans the elaborate activities did not stimulate learners to find real-life connections with the gained knowledge (see Table 3, elaborate item 3). Particularly concerning constructivist learning settings, learning processes should be triggered by real-world problems (Koohang et al., 2009). Taking a look at the design heuristic reveals the connection to real-life is missing in the description of the elaboration phase; this will be considered in the redesign of the design heuristic.

In the phase of evaluation (see Table 3, evaluation item 1–4) teachers' lesson plans performed the worst since not even half of the lesson plans passed the items regarding evaluation. Teachers struggled to choose an appropriate assessment technique, especially when the inquiry was open. These findings confirm the fact that assessing learning through inquiry is a challenge for educators and not uniquely related to the 5E model. To assess open inquiry, rubrics, including scoring criteria, might support teachers in evaluating student performance (Taylor & Bidlingmaier, 1998). Rubrics (e.g. Duran, 2003) are also given as an example in evaluation item 4, which is focusing on the measurability of evaluation criteria.

Most lesson plans included just a self-assessment activity with almost no explanation on how evidence of learning would be collected (see, for example, Table 2). It seems as if the majority of participating teachers think the use of self-assessment is only appropriate and sufficient to assess learning through inquiry. Only a few teachers planned to apply summative assessment, which might be explained by Correia and Harrisons' findings (2019) showing teachers' beliefs about inquiry-based learning are consistent with their actual assessment practices in inquiry lessons. They found out that teachers who are using more open inquiry tend to apply formative assessment; other teachers who tend to implement directed inquiry are more likely to provide evaluative feedback on students' learning.

In the revised design heuristic, the phase of evaluation will include various examples of assessment tools to inspire teachers. Moreover, because of the failed evaluation item three and four, there will be a disclaimer added saying the evaluation criteria should be clear, appropriate and measurable (e.g. use of rubrics for assessment). We still doubt whether the design heuristic alone will enable teachers to assess inquiry-based learning in flipped classroom scenarios adequately. Another professional development course on how to use rubrics for assessing learning through inquiry in flipped classroom scenarios might help teachers, which could be investigated in further research.

5. Limitations

We are aware that our research may have some limitations. To begin with, a small sample size is available in this paper as our study is oriented towards in-depth qualitative research, where usually smaller samples are investigated. According to Bakker (2018), design-based research studies aim for theoretical generalization rather than a generalization from sample to population. The proposed design heuristic as well as the three major categories presented in this paper (see Section 4.1. Identifying didactical patterns among the lesson plans) contribute to the evolving theory of this design-based research study. The three major categories have been identified in a specific context. Besides the design heuristic, the provided lesson plan examples discussed in the online professional development course (see Section 3.2. Procedure of the online professional development course) may have influenced teachers' lesson planning practice and our findings. Additionally, the design heuristic that will be further developed in the course of this design-based research study is contextually sensitive. In further research, the three major categories as well as the developed design heuristic could be validated in various contexts.

6. Conclusion and further research activities

The purpose of this study was to evaluate a design heuristic aimed at supporting teachers in developing flipped classroom lesson plans aligning with the 5E inquiry model. In the context of a three week online professional development course, lesson plans from 18 secondary mathematics teachers who applied the design heuristic were collected. To explore how teachers adopted the design heuristic in their lesson plans, a document analysis (Bowen, 2009) was conducted. Findings indicate that participants planned to use pre out-of-class phases for engagement, post out-of-class phases for consolidation, and in-class phases mainly for the implementation of student-centred activities. Furthermore, analysis according to the 5E lesson plan scoring instrument (Goldston et al., 2013) suggests some descriptions of the proposed design heuristic need to be revised, especially the ones in the phase of evaluation. However, with the help of the proposed design heuristic, the participating secondary mathematics teachers were able to set up flipped classroom lesson plans which were mostly in line with the engage, explore, explain and elaborate phase of the 5E inquiry model (Bybee, 2009).

The research presented in this paper is part of an educational design-based research project (Wang & Hannafin, 2005) aimed at developing a design heuristic for assisting teachers' lesson planning practice regarding inquiry-based flipped classroom scenarios. In the next research cycle, the current design heuristic will be revised according to the results presented in this paper and then re-implemented in professional development. Further research could also examine the usefulness of the design heuristic in science education since the 5E inquiry model is a widely used approach in science education (Bybee, 2009). Also flipped classroom approaches are used more frequently in different science subjects (e.g. Lazendic-Galloway et al., 2016). Moreover, it could be interesting to investigate teaching practice based on lesson plans inspired by the design heuristic because teachers may rearrange the in-class and out-of-class phases depending on students' learning pace.

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