Teaching-learning sequences: A comparison of learning demand analysis and educational reconstruction

Jouni Viiri, **Antti Savinainen**
Department of Teacher Education, University of Jyväskylä, P.O.Box 35, FI-40014 University of Jyväskylä, Finland.

E-mail: jouni.viiri@edu.jyu.fi

(Received 3 January 2008; accepted 4 February 2008)

Abstract

Teaching-learning sequences (TLS) for science teaching have been designed for over two decades and there is a growing interest in them amongst the science education community. Several theoretical frameworks have been utilized in designing TLSs. In this paper we outline two such frameworks: learning demand and educational reconstruction. We compare the learning demand and the educational reconstruction frameworks, present some concrete examples from two studies where these frameworks have been used, and present some general recommendations for developing TLSs.

Keywords: Teaching-learning sequence, learning demand, reconstruction educational.

Resumen

Las secuencia de enseñanza-aprendizaje (TLS) para la enseñanza de las ciencias han sido diseñadas por más de dos décadas y entre la comunidad de educación de las ciencias hay un creciente interés por ellas. Se han utilizado varios marcos de referencia teóricos al diseñar los TLSs. En este artículo describimos dos de tales sistemas de referencia: demanda de aprendizaje y la reconstrucción educational. Comparamos los marcos de referencia de la demanda de aprendizaje y el de reconstrucción educacional, presentamos algunos ejemplos concretos de dos estudios en donde estos marcos de referencia se han usado, y también presentamos algunas recomendaciones generales para desarrollar TLS.

Palabras clave: Secuencia de Enseñanza-aprendizaje, demanda de aprendizaje, reconstrucción educacional.

PACS: 01.40.Fk, *01.40.gb,* 03.65.-w **ISSN 1870-9095**

I. INTRODUCTION

Designing teaching-learning sequences (TLS) for science teaching has been going on for over two decades and there is growing interest in it amongst the science education community. The design work done has concentrated on investigating the teaching and learning of single science topics rather than whole curricula [1]. Since the TLSs developed have dealt with single science topics content-specific knowledge is necessary in designing TLSs. General constructivist and sociocultural theories can provide general guidelines for designing TLSs but they are insufficient when designing a teaching sequence for a given topic in detail [2].

For designing TLS several theoretical frameworks have been utilized [1]. We have experience in using two such frameworks in designing teaching-learning-sequences: learning demand [3] and educational reconstruction [4]. These frameworks seem to be somewhat different as they are inspired by different learning theories. There is no systematic comparison of similarities and differences of these two frameworks in the research literature even though they are discussed to some extent in a review paper by Meheut and Psillos [1].

In this paper we first outline these frameworks and present examples from two studies where these frameworks were used. We do not outline the research questions nor the learning outcomes of these studies since they have already been published [5, 6]. Then we provide a comparison of the frameworks to help science and physics education researchers in finding suitable tools for their designing tasks. We are going to argue that these frameworks share many similarities despite their different underlying theoretical assumptions. However, they might be suitable for somewhat different purposes. We believe that this kind of reflection is important for future development of frameworks for designing TLSs.

II. LEARNING DEMAND

The learning demand approach is underpinned by a perspective on science learning which incorporates both individual and sociocultural views of learning [7]. As Leach and Scott [7] stress, the teacher plays a central role in introducing scientific ideas to the class and in guiding the classroom discourse. The teacher should be aware of and appreciate students' everyday modes of thinking and talking about the topics (pre-instructional or alternative conceptions) which will be taught. The notion of learning demand specifies the differences between the everyday and scientific modes of thinking: it is used in identifying, at a fine-grain definition level, the learning challenges involved in specific domains of science.

In this approach, instructional design starts with an analysis of the science content to be taught. The next step is the learning demand analysis, which addresses differences between everyday and scientific ways of thinking and talking. The learning demand may be due to differences in the conceptual tools, the epistemological underpinnings of the knowledge being used, or certain ontological assumptions. A conceptual learning demand arises when students apply everyday notions (e.g. 'motion implies force') instead of scientific concepts ('acceleration implies net force') in explaining phenomena. An epistemological learning demand arises when students have difficulties in applying conceptual tools in various contexts. This type of learning demand seems to be common, since there is good evidence that student understanding tends to be context dependent (e.g. [8, 9]). An ontological learning demand is created in cases where students perceive a property of a process (e.g. heat, work, force) as a property of objects: this notion has close links to the ontological theory of conceptual change [10]. Hence, the accumulated research into students' conceptions provides an excellent resource in identifying learning demands in various domains of science.

The overall scheme for the learning demand approach can be summarized in the following way [11]:

1. Identify the school science to be taught
2. Consider how this area is conceptualized in the everyday reasoning of students
3. Identify the learning demand by appraising the nature of any differences (conceptual, epistemological, ontological) between 1 and 2
4. Design a teaching sequence to address each aspect of this learning demand:
   - identify the teaching goals for each phase of the sequence
   - plan a sequence of activities to address the specific teaching goals
   - specify how these teaching activities might be linked to appropriate forms of classroom communication.

The last point, about classroom communication, should be interpreted broadly: it includes teacher-student talk and students' peer discussions as well as other forms of communication such as gestures, drawings and different representations (e.g., graphical, diagrammatic and vectorial).

Reports of TLS studies should include an analysis of how the teaching was carried out. [3] One way to do this is to describe the use of talk/discourse during the teaching sequence. The way a teacher and students discuss during the sequence is as important for learning as the actual teaching actions, so communication should be planned as thoroughly as the teaching actions of the TLS. An analytical framework for planning (and evaluating) teaching sequences from the communication perspective has been developed ([12]). The possible communicative approaches (dialogic-authoritative, interactive – non – interactive) and their relations to possible teaching purposes are shown in Figure 1. When planning the TLS, we should also plan which communicative approaches are used.

	Interactive	**Non-interactive**
Authoritative (Focus on science view)	Teacher aims to reach one specific point of view	Teacher presents one specific point of view
Dialogic (Taking account of pupils' understanding)	Teacher tries to elicit students' views and work with different points of view	Taking account of students' ideas. Teacher reviews or summaries students' points of view

FIGURE 1. The communicative approaches and teaching purpose (based on [12])

Now we turn to an example drawn from a science teaching-learning sequence which we have developed and evaluated, as concrete example of how the framework of learning demand was used.

Example of learning demand analysis - Designing a teaching sequence for Newton's third law

In 2005, we published a study on the design and evaluation of a teaching sequence for teaching Newton's third law [5]. This teaching sequence was intended for Finnish high school students (aged 16). Here we present examples of the learning demand analysis and design of some teaching aspects.

Identification of the learning demand was based on the differences between the school science to be taught and how this area is conceptualized in the students' everyday reasoning. The learning demand analysis for the force concept is illustrated in Table I.

TABLE I. Learning demand analysis: the force concept [5].

Aspects of school science to be addressed	**Typical everyday views of students**
Ontological aspect: Force is a property of an interaction between two objects.	Force is an innate or acquired property of objects (impetus).
Conceptual aspect: Interaction between two objects implies that they exert forces on each other: forces always come in pairs.	Inert or inanimate objects cannot exert forces.
Epistemological aspect: The notion of symmetrical interaction between two objects (i.e., Newton's third law) is generally applicable to *all* situations.	Newton's third law is used in some situations but not others (where, for example, the dominance principle may be applied) depending on the contextual features of the situation at hand.

In order to meet the requirements of the learning demands we adopted the "symbolic representation of interactions" (the SRI diagram or interaction diagram) developed by Jiménez and Perales [13]. It permits a strong, visualizable emphasis on forces as interactions throughout the teaching. An example of an interaction diagram is shown in Figure 2: it represents a block being pulled by a spring balance along a table. The block is in contact with the table and the spring balance, hence there are two contact interactions. The single contact interaction between the block and the table is divided into two "sub-interactions": one represents the frictional interaction (the horizontal component) and the other normal force interaction (the vertical component).

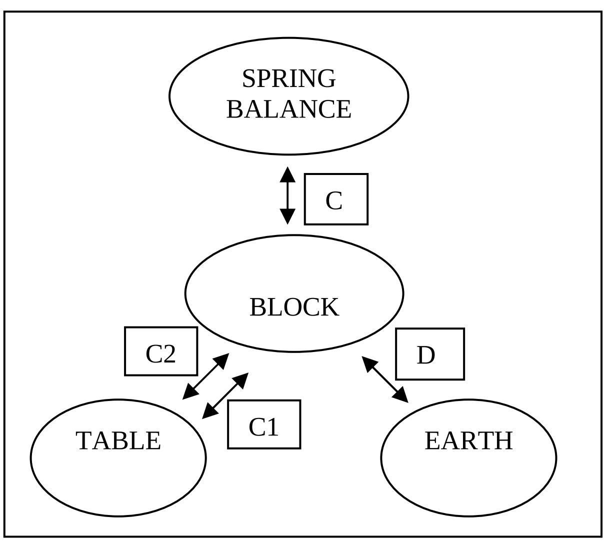

FIGURE 2. An interaction diagram for a block being pulled along the surface of a table using a spring balance. Contact and distance interactions are denoted by "C" and "D", respectively. C1 = normal force interaction, C2 = frictional interaction.

The interaction diagram makes it possible to address all the aspects of the learning demand. It provides a tool for identifying and representing interactions between objects, which helps students to perceive forces as a property of an interaction instead of a property of an object (the ontological aspect). It also shows by means of the double-headed arrows that an interaction between two objects is symmetrical (the conceptual aspect). Furthermore, applying the SRI diagram in a variety of situations helps students to realize that Newton's third law really is valid in all situations regardless of contextual features (the epistemological aspect).

These teaching activities are linked to appropriate forms of classroom communication. The diagram was initially introduced using 'authoritative discourse', whereas the diagrams were rehearsed using 'dialogic discourse'.

We have now described the general ideas of the learning demand analysis and given an example of how to use it. Next we present similarly the basic ideas of the educational reconstruction framework and an example of using it.

III. EDUCATIONAL RECONSTRUCTION

Educational reconstruction focuses on the reconstruction of science knowledge in order to help students understand the key points. The overall aim is to identify the connections between scientific knowledge and the students' alternative frameworks in everyday life [14], [15]. Scientific knowledge is, of course, the result of a process of abstraction and reduction, but teaching science involves making the science point of view understandable and meaningful to learners, hence the term 'reconstruction'. The first step is to clarify the structure of the scientific knowledge or the subject matter. The term 'educational' reconstruction is justified here because the analysis of content structure is influenced by educational issues: there is a close interplay between the clarification and investigation of students' perspectives (see Figure 3).

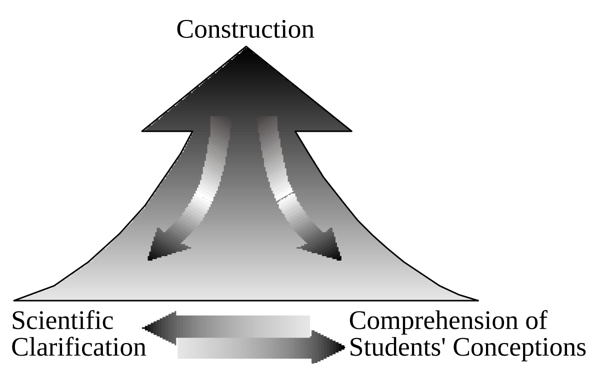

FIGURE 3. The dynamic interrelations of the model of educational reconstruction [14].

The second step in educational reconstruction is 'elementarisation' (Figure 4), where the aim is to identify the key 'elementary' ideas of the science content concerned.

The analysis and reconstruction of the science content are based on the analysis of leading textbooks, key publications and even the historical development of the relevant scientific ideas [4]. Some studies on learning science can also be used as an entry point for the analysis of the science content. Clarifying questions are used in the analysis process, for instance [14]:

- What scientific theories, principles and concepts are involved in a specific subject, and what are their limitations?
- Which scientific terms are used, and which ones constrain or promote learning just because of their literal meaning?

The term 'content' is used in the model with a somewhat broad spectrum of meanings. It includes not only science concepts and principles but also science processes, and views of the nature of science and of the significance of science in society.

Educational reconstruction also includes investigation of students' understanding of the basic ideas. This could take the form of empirical investigation and/or a literature search. The results concerning students' learning processes and learning difficulties inform the construction of the content structure for instruction and the design of efficient learning environments as well [4]. Affective features (such as students' interests and motivations) have been given only minor attention so far.

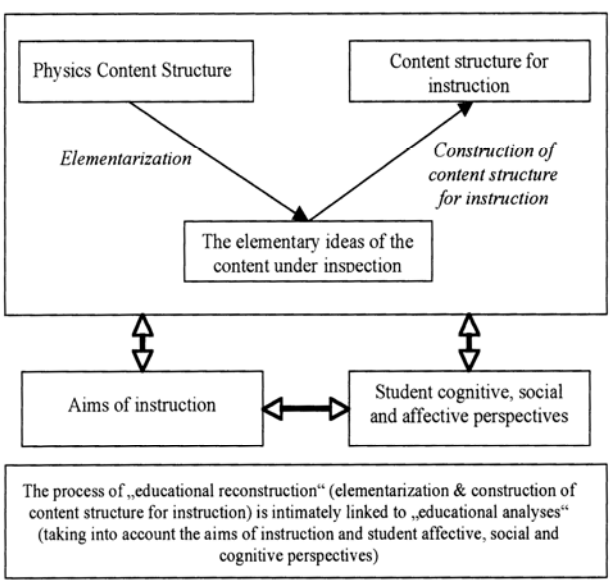

FIGURE 4. The interdisciplinary nature of educational reconstruction [15]

Clarifying questions are also used in identifying important conceptions students hold regarding the target area, for instance [14]:

- How are the scientific concepts represented from the students' perspective?
- Which conceptions are used by the students?
- How do alternative student conceptions correspond with scientific conceptions?

One important feature of educational reconstruction is that the reconstructed science content is "simpler" than the science content, *i.e.* the scientific content is changed to make it accessible to students. The major features of scientific ideas and their relationships should be adequately matched in the reconstructed science content [4]. On the other hand, the reconstructed science content has to be much more complex than the abstract science content which has to be embedded into various contexts ('enriching') in order to correspond to the learners' difficulties and learning potentialities.

In the construction of instruction students' conceptions should be taken seriously. These conceptions and alternative frameworks in everyday life are taken as a starting point and an aid for learning. Hence, the educational reconstruction approach relies on students' existing ideas and aims to extend them to a new domain in order to promote conceptual change. It might be very difficult to take into account the whole complexity of interrelated issues in a holistic manner from the very start [4], so there has to be some kind of iterative procedure, as outlined in Figure 5.

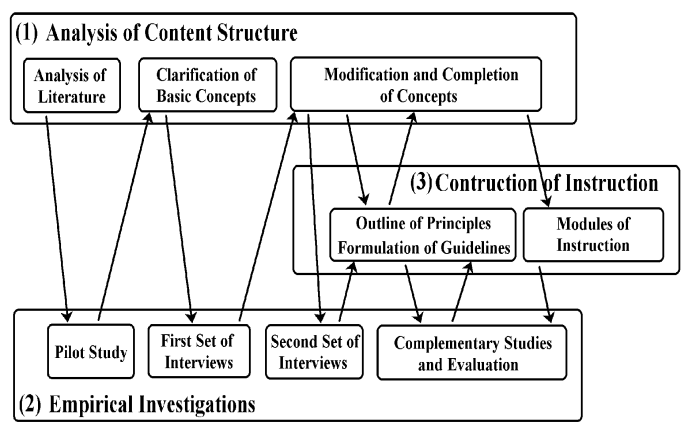

FIGURE 5. The process of Educational Reconstruction [4].

The next step is dealing with the construction of the content structure for instruction based on these key elementary ideas. Both parts of the process of the educational reconstruction are significantly influenced by the students' perspectives and the aims of instruction. These aims are usually provided by the curriculum. Subsequently, the aims may be understood in terms of level of detail and mathematical abstraction at which the given science topic should be dealt with.

Next we present an example how educational reconstruction was used in designing a TLS on the tides.

Example of educational reconstruction – a teaching unit on the tides

This TLS was a new teaching unit dealing with tides as part of an 8th grade (age 14) astronomy course at a Finnish secondary school. Here we report the main factors involved in developing the unit. For a more thorough discussion see [6].

The design procedure was cyclical, not linear, and there were many interactions and iterations between the three phases (Figure 6).

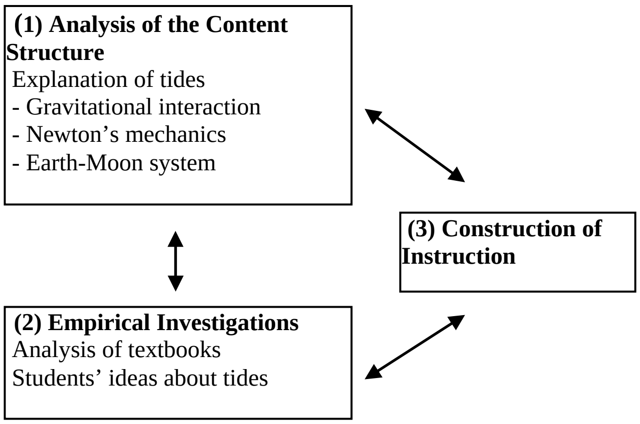

FIGURE 6. Educational reconstruction applied to the development of teaching and learning about tides.

The aim of the content structure analysis was to identify the most important ideas and concepts that could be used in describing tides at lower secondary school level. Basically, all the theories explaining tides are based on the fact that the gravitational force depends on the distance between the bodies that are in gravitational interaction. The Newtonian law of gravitation implies that the force will be stronger the closer the bodies are to each other: for instance, the Moon's gravitational force will be stronger the closer we are to it. Consequently, the Moon's gravitational force is stronger on the side of the Earth facing the Moon than it is on the other side. The effect of these differential forces (the gradient of the Moon's gravitation) is to distort the water level on each side of the Earth. We also analyzed the history of explanations of tides. The different theories developed over the centuries provided us insights about the hardest parts of the scientific explanation regarding different aspects of tides and ideas for possible explanation for the students.

The modification and reconstruction of the scientific explanation was based on the scientific explanation and on knowledge of the students' conceptions. We had gathered students' explanations of tides, analyzed them, and used this information in the modification. The teachable content structure was then focused on two main phenomena:

- First, there are two simultaneous tidal bulges on opposite sides of the Earth. This can be explained by the gradient of the Moon's gravitation and the Earth's movement (free fall) in the Earth-Moon system.
- Second, high tide occurs every 12 hours. This is caused by the Earth's daily rotation around its axis and by the two tidal bulges.

Our empirical investigations included examining students' ideas about tides, textbook analysis, and conducting teaching experiments at school. A questionnaire was used to find out students' spontaneous ways of explaining and understanding tides. The aim of the textbook analysis was to discover what types of explanations are provided in textbooks, how the explanations are related to scientific explanations, and how the textbook explanations take into account the learning difficulties that students might have.

After completing the modification of the scientific concepts, textbook analysis, and analysis of students' ideas, we conducted two teaching experiments. In the first one we tested our ideas, and in the second one we made some modifications based on our experience in the first study. Since the textbook analysis was based on students' ideas and scientific ideas, and on the other hand scientific ideas were reconstructed based on the knowledge of students' ideas, the design process was cyclic.

IV. COMPARISON OF THE TWO APPROACHES

We have described the general principles of learning demand and educational reconstruction. The two approaches are compared in Table II.

The approaches share many similar features, but there are also some differences. The role of educational theories is important in both frameworks. The educational reconstruction idea is based on the German Didaktik tradition but explicitly viewed from recent constructivist perspectives. One of the ideas of this tradition adopted in educational reconstruction is that of a fundamental interplay of intentions of instruction, topic of instruction, methods of instruction, and media used in instruction. (See more about this tradition in [16]). Based on the published articles it may be concluded that the constructivist perspective utilized in the educational reconstruction places more emphasis on the individual constructivism than on the social constructivism. The learning demand idea draws on the socio-cultural perspective on learning, in which science learning can be described as an ability to use concepts appropriately in different contexts [7]. This perspective's main effect is on theorising classroom communication in teaching and learning [12].

Neither of the frameworks explicitly states the teaching methodology that should be used in the actual classroom situation. However, in teaching sessions based on the learning demand approach we would expect great effort in terms of interactivity (including both discourse among students and between students and the teacher), since the framework is closely connected to the communicative learning approach [12]. Analysis of the classroom communication is also related to the teaching purposes and consequently to teaching methodology. Therefore the learning demand analysis combined with the communicative approach has more to say about teaching in the actual classroom situation than does educational reconstruction.

TABLE II. Comparison of the learning demand and educational reconstruction approaches.

	Learning demand	**Educational reconstruction**
Role of the science content	less systematic analysis of the science content. The science content to be taught is framed by making use of research on students' everyday thinking.	a starting point: analysis initially only from the point of view of science; the historical development of the scientific content is also considered
Role of educational theories	based on Vygotskian ideas and the socio-cultural framework	draws on the German "Didaktik" tradition and culture of pedagogy and science education
Role of history of science	not particularly important	important in reconstructing the science content
Students' ideas	regarded as a valuable aid to teaching/learning; divided into conceptual, epistemological, ontological aspects; included in learning demand analysis and planning the teaching	regarded as a valuable aid to teaching/learning; taken into account during the elementarisation and when the science content to be taught is reconstructed
Students' motivation	not explicitly mentioned	mentioned explicitly together with attitudes
Teaching methodology	not explicitly mentioned, but related to the communicative analysis	not explicitly mentioned
Cyclic process, iteration	not mentioned	yes
Science content vs. school science content to be taught	a teaching analogy (simplified model) may be developed to address the learning demands identified	"simpler" than the science content structure; the major features of the science content are adequately matched
Aim	to develop an evidence-based TLS	to develop an evidence-based TLS

In both frameworks it is essential to take students' preconceptions into consideration when planning the TLS. The learning demand describes the difference between students' conceptions and the school science view. The demand is identified using three aspects: conceptual, epistemological and ontological. The same aspects are taken into account in the educational reconstruction but not explicitly.

The analysis of science content seems to be emphasised more in the educational reconstruction than in the learning demand approach. Educational reconstruction also takes into account the history of science. Studying the historical development of the topic to be taught could provide hints on how to teach it so that it helps students' learning.

Educational reconstruction has a built-in iterative process, whereas the learning demand approach seems to be more linear. In practice, however, there certainly are features of the iterative process also in the learning demand approach.

The learning demand analysis does not explicitly mention the motivational aspects in designing the teaching sessions. This might be the result of the belief that good teaching as such motivates students to learn: in fact, there is evidence that motivation can come from teaching which is successful in fostering conceptual understanding ([11]). The learning demand approach addresses various forms of classroom communication, and this may motivate students since their views and explanations are sought and welcomed by the teacher. Consequently, there is no need to have more practical work than typically and the phenomena under study need not be familiar or interesting to students before the teaching. The educational reconstruction framework attempts to take into account affective perspectives, such as students' interest, self-concepts and attitudes [16]. However, it is not easy to see how these perspectives can be incorporated into a teaching-learning sequence.

V. DISCUSSION

We have described the general principles of learning demand analysis and the educational reconstruction in developing TLSs. There are differences between these two frameworks but it seems that they fit quite well together and support each other.

Educational reconstruction constitutes a global framework for developing research-based TLSs. For instance, it refers explicitly to the history of science and to an analysis of the literature. It focuses mainly on the reconstruction of scientific knowledge. While learning demand analysis is not so global, it provides more detailed guidance for the development of the actual TLS. Learning demand analysis could be said to be more detailed or "fine grained". When used together with the communicative approach, it combines classroom communication with teaching purposes. For instance, the planner should decide what learning activities will be used and how they are related to classroom communication. We believe that this is a very important aspect in any TLS. It is not enough to pay attention only to the design of the instructional sequences: the role of the teacher in staging those teaching activities and orchestrating various forms of talk must also be addressed [3]. Leach [11] goes on to state that "the challenge for transferring research insights from one site to another lies in enabling teachers to recognise which features of a design are central to its rationale, and therefore should be modified with extreme caution, and which features are less critical."

The differences mentioned – the global aspect of educational reconstruction and the fine grained detail provided by learning demand – were evident also in the examples given. Since Newton's third law is a very specific topic, the learning demand analysis is appropriate for that case. In contrast, the tides are very many sided so educational reconstruction might be a more suitable framework for designing a TLS for this topic.

Both the frameworks discussed here stress that domain-specific research is necessary for designing effective learning experiences, for (at least) two reasons. Firstly, TLS should take into account the most common student difficulties in a given domain, since numerous studies provide evidence of common misunderstandings in many science domains [17]. Secondly, conceptual development does not follow the same routes in different science topics [18]. Also both learning demand analysis and educational reconstruction are based on the idea that content-oriented theories are a necessary complement to theoretical platforms such as constructivist and the socio-cultural approaches.

ACKNOWLEDGEMENTS

We wish to thank Reinders Duit, John Leach and Phil Scott for their helpful comments on the first draft of the paper.

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