TOWARDS EVALUATION CRITERIA FOR COHERENCE OF A DATA-BASED STATISTICS CURRICULUM

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As coherence is one of the objectives of a new data-based statistics curriculum for grades 10-11 (age 15-17) in the Netherlands, this paper explores the notion of curriculum coherence. Although policy-makers and educators around the world look for more coherent curricula, it is often not clear what this actually means. This paper works towards an operational definition of a coherent statistics curriculum by analyzing the results of interviews and email discussions with national and international experts on statistics education who were asked for their opinions on what constitutes a coherent statistics curriculum. The results are a first step towards evaluation criteria for coherence of the three common representations of a curriculum: the intended, implemented and attained curriculum.

INTRODUCTION

Education policy documents and curriculum standards in various countries strive for more coherent curricula (National Council of Teachers of Mathematics, 2006; Newmann et al., 2001; Nixon, 1991). A more coherent curriculum could help students gain deeper understanding of the important ideas in science (Bransford et al., 2000; Shwartz et al., 2008). In the Netherlands more coherence within and between the curricula for different parts of science and mathematics is also one of the objectives of a broader reform movement in secondary education (cTWO, 2007). It is within this movement that a new statistics curriculum has been proposed for grades 10-11 (age 15-17) of senior general secondary education.

What is new in this curriculum is the focus on learning statistics by a data-based and problem-oriented approach. The reform follows similar movements in other countries (e.g., USA, Germany, and New Zealand) and is inspired by international research in the field of statistics education. Teaching students a list of statistical recipes is not enough to make them statistically literate. Students also need to see the coherence in the concepts they learn and in the basic principles underlying data analysis (Moore, 1997; Tarr & Shaughnessy, 2007). In the new curriculum, to be implemented in 2014, teachers are encouraged to let students work with real data sets and information technology. Furthermore, the curriculum has both a theoretical and a practical strand. In the practical strand students do research projects where they can apply to real-world problems the theoretical concepts they have learnt in the theoretical strand.

Problem statement

In order to know whether the new statistics curriculum will indeed be more coherent, criteria are needed to evaluate its coherence. In this paper, curriculum is defined as a *course or plan for learning* (cf. Taba, 1962; Van den Akker, 2003). Since no operational definition of a coherent curriculum exists (Newmann et al., 2001), it is necessary to develop one. In the online Cambridge Dictionary *coherent* is defined as: “If an argument, set of ideas, or a plan is coherent, it is clear and carefully considered, and each part of it connects or follows in a natural or sensible way”. This definition can be applied to a curriculum; however, it is still not operational. One of the problems is that a curriculum has various representations; another is the huge gap between the original ideas and intentions of a new curriculum and the curriculum actually enacted in classrooms (Van den Akker & Voogt, 1994; Begg, 2005). Thus, a thorough evaluation of a new curriculum should look at different representations of a curriculum.

There are three common representations of a curriculum: the intended, implemented and attained curriculum (Goodlad, 1979; Van den Akker, 2003). The intended curriculum is represented by curriculum documents and instructional materials, the implemented curriculum by teaching and learning activities actually enacted in classrooms, and the attained curriculum is represented by students’ learning experiences and learning results.

When educators are asked what a coherent curriculum is and how to distinguish among the different representations, the response will be different for each of the representations. In the intended and implemented curriculum, coherence *has* a purpose; it aims at developing coherent knowledge in the attained curriculum. In the attained curriculum, coherence *is* the purpose: students' coherent knowledge. These considerations lead to two research questions:

1. What do people mean by coherent statistical knowledge?
2. How can coherence of students' statistical knowledge be advanced?

The generic measures described in response to the second question can form the basis for more specific and observable evaluation criteria for coherence of the intended curriculum and the quality of its implementation. However, coherent statistical knowledge is not something that can be observed. Therefore other ways to measure this type of coherence are needed, hence a third research question:

3. How can coherence of students' statistical knowledge be measured?

CURRICULUM COHERENCE IN LITERATURE

Most of the literature on curriculum coherence is not specific for statistics education and often discusses coherence between different subjects. Shwartz and colleagues (2008) do give useful recommendations for improving what they call learning goal coherence: focus on the key concepts, take students' beliefs and prior knowledge into account, engage students with relevant phenomena, and support students' understanding and reasoning skills.

Literature on coherence in statistics education is very scarce. Sowey (1995) discusses coherence in statistics education in the light of making the subject memorable, i.e. that the central ideas will be long remembered. He distinguishes three types of coherence: theme coherence (not only the principles of a technique but also its practical applications), pattern coherence (underlying unity in disparate procedures), and knowledge coherence (integration of statistics with other disciplines). In another article (Sowey, 1998), he gives examples of how teachers can reveal these different types of coherence to students by means of perspective views, i.e. approaches that illuminate the purpose and structure of statistics. Other literature on statistics education that seems relevant to our purpose does not mention the notion of coherence or coherent statistical knowledge explicitly. This point is considered again in the discussion section of this paper.

METHODS

To make up for the lack of literature on coherence in statistics education, experts in the field were interviewed, assuming that a synthesis of their ideas would provide answers to the focus questions. Five Dutch experts who were involved in the development of the ideas behind the new curriculum and its core objectives were asked for their opinions of what constitutes a good statistics curriculum and what role the notion of coherence has in this picture. They were explicitly asked to give a definition of a coherent curriculum and how it should be implemented so that students could indeed experience a curriculum as coherent (i.e. course of learning). All interviews were audio-recorded and transcribed.

In order to have a more international view on these issues an email was sent to 24 international experts on statistics education. The email gave some background information on the project and asked questions concerning their ideas on how to make a statistics curriculum more coherent, what kind of teaching and learning activities could lead to more coherence, and how coherence can be measured. Replies from seven researchers led to a more thorough discussion and exchange of ideas, five by email and two by face-to-face interviews. These interviews were also audio-recorded and transcribed.

The interview transcripts and email discussions were analyzed using Atlas TI, a computer software application for qualitative analysis of texts. The analysis began with open coding and afterwards the codes were organized in a number of coding families related to the research questions: coherent knowledge, coherence of intended curriculum, learning activities, teacher guidelines, and ideas for assessment. Since the interviews with the Dutch experts were initially about their ideas of good statistics education, a coding family was created for that issue as well. The coding families made it possible to retrieve, summarize and report the essence of all answers given.

RESULTS

The results of the analysis of the email-discussions and all face-to-face interviews are presented below in three sections relating to the three research questions.

1. Notions of coherent statistical knowledge

Different opinions emerged about what constitutes coherent statistical knowledge. Many responses referred more or less directly to *conceptual understanding*, often accompanied by terms such as *transfer* or *knowing when to use what*. One response stated:

> We need more attention for statistical concepts instead of techniques and tricks. Almost all literature is complaining about the fact that students learn how to calculate the mean but do not know how to compare two groups. They don't even realize that they can use the mean for that.

Conceptual understanding is having mental connections between mathematical facts, procedures and ideas (Davis, 1984; Hiebert & Carpenter, 1992). The association of conceptual understanding with transfer or knowing when to use what is in line with Bransford and colleagues (2000). They underlined the importance of such a rich network of mental connections for students to be able to know when to make use of their knowledge appropriately and to transfer their knowledge to new and unknown applications or domains.

Some respondents explicitly considered *meta-cognition* or having an *overview of statistical concepts* part of coherent statistical knowledge and in explaining their opinion established a connection to the notion of *statistical reasoning*:

> These purposes, they can be supported by a lot of reflection, meta-cognition, discussions. Otherwise, if you don't make it explicit…students don't realize that there are principles that underlie the whole thing: our ways of thinking (…) that are typical of statistical reasoning.

2. Advancing coherence of students' statistical knowledge.

In response to the question about how the development of students' statistical knowledge can be supported, many respondents indicated that the curriculum lines themselves should be coherent in the sense that they are organized around *central themes*, for instance the *key concepts*, or *big* or *powerful ideas* of statistics. Another respondent, however, stressed that organization of the curriculum around the big ideas is not enough, but that it is also important to develop these concepts by a *concentric method*, i.e. topics should recur several times in a curriculum. This opinion was endorsed by many other respondents, as is illustrated by this statement: "There's an old "rule of thumb" in teaching that students never really understand what you teach until the next class, where they see it again in a new context." One way mentioned by several respondents to organize the curriculum is using a *concentric method* around ever *recurring topics*, recognizing that there are *two basic types of statistical questions*: either you want to know whether a certain variable is correlated with another variable or you are comparing two or more groups.

Some respondents argued that coherence might also result from the *approach* taken in a curriculum. This may be an inquiry-based approach or other approaches, such as project-based learning or problem-based learning. These approaches have in common that they all recognize that statistics is done with a *purpose*. The coherence comes from the approach in which statistical concepts recur naturally again and again:

> So, all these statistical concepts that we want to teach come up very organically, very naturally in the investigation. And through doing these kinds of investigations again and again over the years, students develop a sense of what a mean is for, what it's used for, when to use it, et cetera.

The Dutch respondents often mentioned that it is important to make the *relation between chance and statistics* more explicit; in the old curriculum these were two separate worlds.

Thus, the results produced several ideas to develop a coherent statistics curriculum and organize coherent instructional materials. However, a coherent intended curriculum is not sufficient. Its enactment requires ideas for classroom activities and teacher behaviour that support students in developing coherent statistical knowledge.

Many suggestions for learning activities directly relate to the organization of the intended curriculum. When the intended curriculum is inquiry-based, it is natural to let students do *statistical inquiries*. Respondents also associated *engagement* or a *motivational factor* in doing inquiries and raised the importance of letting students work with their own data:

> And there is something about having to collect the data yourself and organize it. That is a very powerful experience for building students' ability to be sceptical when they see data. Or to be able to see a representation, or see a graph and make meaning of it, whereas it is just usually we start with the data already collected and they don't learn to think about the history of where the data come from.

The underlying assumption seems to be that projects or inquiries can strongly *motivate* students and support them in becoming *active learners*, so that they connect statistical concepts and techniques in such a way that they are able to apply them in a correct way in different contexts. Furthermore, projects or inquiries can help to develop a *critical stance* so that students become *statistically literate*.

One of the respondents connected the notion of statistical literacy with *developing habits and norms* of working with data and a *different classroom culture*. However, what should teachers do in order to develop such a different classroom culture? According to many of our respondents, giving room for *discussion* and *reflection* and asking students to give *arguments* for the things they say and do are important factors:

> The students have to be encouraged to ask questions and to be curious and to persevere, to not give up quickly when they don't find a solution when something surprising happens, and that happens a lot with dirty data. Data could bring that as well.

Discussion and reflection are also mentioned as ways to support the development of meta-cognitive skills, and both are well-known methods to stimulate *active learning* (Bransford et al., 2000).

Many respondents mentioned the role of *computer software* in a statistics curriculum. Of course, computers are an important aid while working with data sets, but some respondents also made remarks on the role of computer software in developing conceptual understanding, for example software programs that let students *visualize* data:

> There are some really nice educational software programs that let you visualize data, so you can see the distribution without formalizing it. You can choose certain cases and see where they show up in the distributions, and it builds some inferential thinking…When the time comes to formalize it, students have the experience to draw on and they know when to use it. Whereas, if you formalize it first, then there's a loss of understanding, 'cause they don't know why they really need it. They'll just do it.

This example also has a strong association with the notion of *active learning* and *motivation*, as does the advice given by one of the respondents to *build on students' current (possibly naïve) knowledge* of statistical issues:

> Such an approach might assume that students need to build from their current knowledge base and therefore the curriculum would need to pay at least as much attention to what students already know as to what it is that they need to learn.

3. Measuring coherence of students' statistical knowledge

Respondents agreed that measuring the coherence of students' statistical knowledge is very difficult. Several well-known ideas, such as concept maps, rubrics and statistical reasoning assessment were mentioned, but there was little agreement among the respondents, and in most cases, respondents had little experience with these types of assessment methods. Some argued that making statistical inquiries part of the assessment procedure could help in assessing coherence of students' knowledge:

> The way to assess whether they can make inferences, and whether they have habits of inquiry and statistical habits and norms, is to give them an inquiry and see what they are doing…There is also a written report of their investigation. That will show a little bit of the process of their thinking, you will be able to know a bit more about the way they actually used their statistical knowledge in solving some problem.

Two suggestions for the kind of knowledge on which an assessment for coherent knowledge should focus are recognizing students' way of thinking and their ability to make sound inferences. Another idea that falls into this category is assessing whether students' recognize interrelationships between statistical methods. However, the following quote illustrates that these ideas are not easy to bring into effect:

> It seems that when someone says something or does something that is recognisable in your own way of thinking, we might acknowledge this match. Indeed, we might define coherence as a recognition of such a match. But it does not seem reasonable to me to argue that when someone does not do that thing, they do not have an understanding. It probably means that you as the observer do not recognise their understanding.

Table 1 provides a descriptive summary of the results; it is not meant to be a normative framework.

Table 1 Summary of results

What is coherent statistical knowledge?	• Conceptual understanding, knowing when to use what, transfer, meta-cognition, overview, statistical reasoning
How can coherence of students' statistical knowledge be advanced?	*Intended curriculum* • Build around central themes (key concepts, recurring subjects, two types of questions) • Emphasize the purpose (inquiry-based or problem-based curriculum) • Make relationships between chance and data explicit
	Implemented curriculum • Motivating learning activities (statistical inquiries, own data, build on existing prior knowledge) • Activating teaching (discussion, reflection, different classroom culture) • Using computer software for visualization
	Attained curriculum • Motivation • Active learning
How can coherence of students' statistical knowledge be measured?	• Concepts maps, rubrics, statistical reasoning assessment

CONCLUSION

The results summarized in Table 1 show that the notion of coherence is linked to several central ideas in educational theory, such as conceptual understanding, meta-cognition, problem-based-learning, motivation and active learning. More specifically, some experts relate coherent statistical knowledge to statistical literacy and statistical reasoning. This opens up a whole new world of literature that can inspire research into coherent statistics curricula.

The results of this study are a first step towards an operational definition of a coherent statistics curriculum. The answers to the second research question can be translated into evaluation criteria for coherence of the new intended statistics curriculum and how it is enacted in the classroom, by making the criteria more explicit and specific. For instance, the generic advice that a coherent statistics curriculum emphasizes the purpose of what is learnt can be translated into the more specific rule; for example, in the instructional materials or the lesson where students learn how to calculate the mean, explicit attention can be given to the purpose of the mean and its relation to other measures of centre.

To find ideas on how to translate the generic advice into specific criteria for statistics education it is necessary to go back to the literature, but now with the additional search for literature on statistics education that aims at developing conceptual understanding, meta-cognition, or statistical reasoning. This insight can also help in the search for ideas to develop an assessment method for coherent statistical knowledge. The methods suggested by the respondents are indeed promising but need further elaboration since there is little experience with these methods.

In conclusion, many of the terms mentioned by some respondents as characteristics of good (statistics) education were related by other respondents to notions or ideas about coherence. So, according to the respondents, striving for a coherent statistics curriculum indeed implies improving the quality of statistics education and perhaps even the reverse.

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