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On pre-service secondary teachers' mathematical content knowledge in statistics

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In this paper we report on the use of a pre-post-test design to study pre-service secondary mathematics teachers' mathematical content knowledge in statistics before and after their first university course in statistics. The results show that the participants were successful in the pre-test on items related to sampling, probability and the general logic of making formal statistical inferences, but struggled with items concerning distributions. Comparing the pre- and post-test reveals an increasing average of the participants' scores in most statistical areas, but that topics like informal statistical inferences and distributions remain challenging for the majority of the participants.

Introduction

The technologies of today collect and make vast quantities of data easily available. However, data itself does not tell us anything, but requires being organized and looked at using models to provide information and knowledge. Now more than ever models are needed in private and professional settings to interpret and make sense of data in various forms (Manyika et al., 2011). In this context, understanding a range of statistical topics and learning statistical reasoning are invaluable tools for all students to become proficient with, in order to enable them to interpret and make sense of data (Franklin et al., 2007; OECD, 2013). In Sweden, students in grades 7–12 learn about randomness, probability, descriptive statistics, measures of spread, correlation, causality, regression, and the normal distribution (Skolverket, 2011a; 2011b). However, learning statistics has proven to be challenging. Research has shown that students, as well as teachers, often poorly understand the statistical procedures they learn, and additionally have difficulties in interpreting graphs and making inferences from data (Bakker & Derry, 2011; Batanero, Burill & Reading, 2011; Shaughnessy, 2007). In line with the argument by Ball, Thames and Phelps (2008), it is important that teachers have a solid understanding of statistical content knowledge to be able to teach the statistics syllabus in schools successfully. Although Batanero et al. (2011) highlighted the lack of adequate research related to both pre-service and practicing teachers' statistical content knowledge, some studies suggest that pre-service secondary mathematics teachers (P-SSMTs) struggle with learning statistics (Lovett & Lee, 2018).

In this paper we contribute to the understanding of P-SSMTs' statistical content knowledge, and investigate if there is any merit to the claim that P-SSMTs struggle with the statistics course(s) in their teacher training programmes as noted by Lovett and Lee (2018). To do this, we investigate a class of Swedish P-SSMTs' statistical content knowledge using a pre-post-test design.

Aim and research question

The aim of the study presented in this paper is twofold: (i) to provide a snapshot of P-SSMTs' statistical content knowledge when they are admitted to the teacher training programme and before having taken any university courses in statistics; and (ii) to identify how the P-SSMTs' strengths and weaknesses of their statistical content knowledge found in (i) change (if at all) after their first university course in statistics. To this end, we investigate the following two research questions: (RQ1) *What statistical content knowledge do P-SSMT display before their first university course in statistics?* and (RQ2) *How does? P-SSMTs' statistical content knowledge change as the result of participating in a university course in statistics?*

Previous research on P-SSMTs' statistical content knowledge

In their review of the literature on teachers' and pre-service statistical content knowledge, Lovett and Lee (2018) conclude that research to date primarily focused on (pre-service) elementary teachers' statistical content knowledge, whereas literature investigating P-SSMTs' statistical content knowledge is spares. Within the limited literature on secondary (pre-service) teachers' statistical content knowledge, Lovett and Lee (2018) identifies 3 main research areas focusing on: (1) computations, algorithms and procedures; (2) insufficient reasoning skills; and (3) obstacles around interpreting and developing graphical representations. The main results from these areas are that P-SSMT are well equipped when it comes to using procedures and algorithms for computations, such as calculating mean values. However, the repetitive focus of standard procedures in mathematics and statistics courses in the teacher training programmes tend to have a negative impact on (pre-service) teachers' statistical content knowledge in terms of their statistical reasoning skills and abilities to make interpretations of graphical representations. In particular, understanding and interpreting box plots and histograms, analyzing skewed distributions, sampling distribution, variability, confidence intervals and p-values, as well as reasoning about, and making inference between, sample- and population distributions pose difficulties (Lovett & Lee, 2018).

The general remark above regarding the spare research on teachers' and P-SSMTs' content knowledge in statistics is also valid in the Swedish context. However, Nilsson and Lindström (2013) profiled 43 (whereof 18+6 secondary teachers) Swedish teachers' knowledge base in probability. They found that the teachers' "knowledge profile is more computationally oriented that conceptually oriented" (p. 61), and identified five knowledge profile patterns showing (1) a base level understanding of the classical interpretation of probability; (2) challenges concerning the structuring of compound events; (3) issues with conjunction and conditional probability; (4) having a less degree of specialized content knowledge than common content knowledge (cf. Ball et al. (2008)); and (5) problems with random variation and principles of experimental probability.

Theoretical framework

In this paper we are interested in mapping and assessing P-SSMTs' content knowledge in statistics. Hence, we generally situate our work in the research field of mathematics education as investigating the *common content knowledge (CCK)* within the framework of *mathematical knowledge for teaching (MKT)* by Ball et al. (2008), or more specifically within statistics education research as CCK as understood in the *statistical knowledge for teaching* framework (SKT) by Groth (2013). We use the statistical content in itself as the organizing framework for the analysis, and to be able to capture more nuanced aspects of P-SSMTs' CCK in statistics, we structure the content within the CCK in statistics by departing from the five 'big ideas of statistics' discussed by Pfannkuch and Ben-Zvi (2011): *data*, *patterns in data*, *variability*, *distributions*, and *inference*. These five content topics are not disjoint, but rather important and intertwined facets of what it means to engage in statistical inquiry. For example, and as discussed by Franklin et al. (2007), *probability* and *sampling* are important aspects permeating and connecting all these five 'big ideas'. In addition, and in light of the recent developments within the statistics education research community, we also consider it productive to divide inference to be either *formal* or *informal* (cf. Makar & Rubin, 2009). Hence, we in this paper conceptualize and structure CCK in statistics into 5 areas related to *probability*, *sampling*, *distributions*, *informal inference*, and *formal inference*.

Methodology, method and research setting

To answer the two research questions we draw on previous, but largely unpublished, research experiences based on a research instrument constructed from previously published research and well-documented instruments. The general idea behind this compiled instrument, which we call CIiS (Concept Inventory in Statistics), was to provide a snapshot of the test-taker's CCK in various areas and topics within statistics. Hence, we designed our study around the adaptation and use of the CIiS as a pre- and post-test given to P-SSMTs before and after their first university course in statistics. Before elaborating on the CIiS instrument and its construction further, we will first briefly describe the research setting.

The research setting

The P-SSMTs participating in the study were enrolled in a teacher education programme at a Swedish university. Before taking the pre-test, the P-SSMTs had studied one semester of mathematics covering topics such as algebra, linear algebra, calculus and mathematics education. None of these courses included any statistical content. However, all the P-SSMTs had completed a section on statistics as part of their upper secondary schooling. The upper secondary level mathematics syllabus (Skolverket, 2011b) includes topics such as: *Statistical methods for reporting observations and data from surveys, discussion of correlation and causality, methods for calculating different measures of central tendency and measures of dispersion including standard deviation,* and *properties of normally distributed material*.

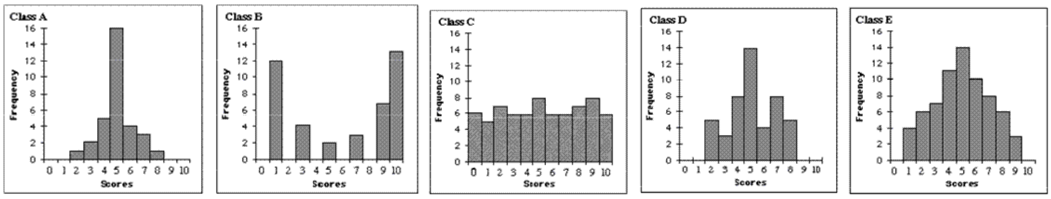
The pre- and post-test were administrated before and after the P-SSMTs took a 8-week course in statistics (among other courses), that was composed of 12 lectures, 12 lessons and 1 laboratory activity using statistical software. The course used and was structured around the textbook by Britton and Garmo (2012), and covered content such *as stochastic variables, probability distributions, expectation values, variance, covariance and correlation, normal and binomial distributions, uncertainty associated with parameter estimation* as and *confidence intervals.*

The pre-test was given to n_{pre}=30 P-SSMTs the day before the first lecture in the statistics course. The time allocated for the pre-test was originally two hours, but since all P-SSMTs finished the CIiS within an hour, only one hour was allocated for the post-test. The post-test data was collected before the final written exam in an extra and voluntary review session for the final exam. Hence, participating in the post-test was not mandatory for the P-SSMTs, and resulted in n_{post}=17 P-SSMTs taking the post-test.

The instrument

The CIiS instrument used for the pre- and post-test was originally compiled as a preliminary diagnostic and design tool for two in-service courses on the teaching and learning of statistics for teachers in the US at the upper secondary level with various backgrounds (Lee et al., 2013). The instrument consists of 30 multiple-choice items organized in 20 question selected from other prior validated instruments. Each item only had one correct answer, but some items have two alternatives (8 items), others three (8 items), four (12 items), or five alternatives (2 items). Of the 30 items on the CIiS, 19 come from the CAOS 4 instrument [*Comprehensive Assessment Outcome in Statistics*] (delMas et al., 2007), eight from the instrument ARTIST [*Assessment Resources Tools for Improving Statistical Thinking*] (http://app.gen.umn.edu/artist/), two from Zeiffler et al. (2008), and one item was added by the instructors of the US in-service teacher course as a complement to one of the CAOS 4 items. See delMas et al. (2007) for a detailed discussion how the items in CAOS 4 and ARTIST were developed, tested and validated. All the 30 items, originally written in English, were translated into Swedish by one of the authors and then proof-read and validated by the other author and an experienced department colleague. Examples of multiple-choice items from the CIiS is presented in figure 1 and 2 below.

Nedan visas 5 histogram över 5 olika klassers provresultat på en skala från 0 till 10 poäng.



Vilken av klasserna har störst standardavvikelse och varför?

A. Klass A, eftersom detta histogram har störst skillnad i höjd mellan staplarna.
B. Klass B, eftersom många av provresultaten ligger långt ifrån medelvärdet.
C. Klass C, eftersom detta histogram har störst antal olika resultat.
D. Klass D, eftersom fördelningen av resultat är spretig och ojämn
E. Klass E, eftersom histogrammet har stor spridning av resultat och ser normalfördelat ut.

Figure 1: Item 5 on the CIiS pre- and post-test: reading and describing a *distribution* (using standard deviation)

To investigate the P-SSMTs’ CCK in statistics, seven subscales were compiled based on: (1) our conceptualization of CCK in statistics (*probability*, *sampling*, *distributions*, *informal inference*, *formal inference*); (2) the specified Measured learning Outcomes of the individual CAOS 4 items in delMas et al. (2007); and (3) the explicit organization and categorization of the items in the ARTIST material – see Table 1 below.

Ett förtag som håller på med familjespel har tagit fram en liten plasthund som man kan kasta som en tärning. Hunden kan antingen landa med alla fyra benen mot underlaget, helt på rygg, eller på sin högra- eller sin vänstra sida. Företaget vet dock inte hur stor sannolikheterna är för de fyra olika utfallen. Vilken av nedanstående metoder är mest lämplig om företaget vill uppskatta de olika sannolikheterna för hur hunden kan landa?

A. Eftersom det finns fyra olika utfall, så kan har varje utfall tillskrivas en sannolikhet av 1/4.
B. Kasta hunden många gånger och beräkna hur många procent av gångerna som de olika utfallen inträffar.
C. Simulera situationen och ta fram data baserat på en modell som har fyra lika sannolika utfall.
D. Inget av ovanstående alternativ.

Figure 2: Item 7 on the CIiS pre- and post-test: probability.

Result

Table 2 in the Appendix shows the P-SSMTs’ result on the 30 items on the CIiS pre- and post-test. We first summarize the P-SSMTs’ CCK in statistics in terms of the pre-test scores for all the n_{pre}=30 P-SSMTs, and then discuss the scores of the n_{post}=17 P-SSMTs completing both the pre- and post-test.

Overall scores on the CIiS pre-test

The distribution of the n_{pre}=30 P-SSMTs' overall score on the CIiS pre-test is displayed in Diagram 1. Out of a maximum score of 30, the n_{pre}=30 P-SSMTs achieved in average a score of $\bar{x}$ = 17.13. The standard deviation was σ = 3.46. The 25th percentile is 14.75 and the 75th percentile is 20.00.

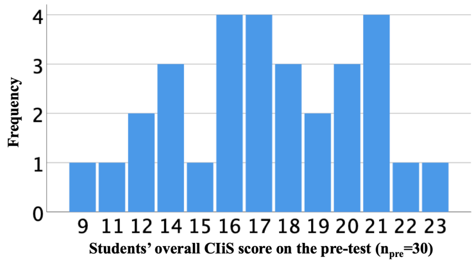


Diagram 1. P-SSMTs' overall CIiS scores on the pre-test.

The three items on the CIiS pre-test on which the P-SSMTs were most successful focused on the *probable sampling outcomes given an explicit distribution of a population* (93.3%, item 12B), *interpreting a probability statement in a real world context* (90.0%, item 8), and *drawing an inference based on the outcome of a described experiment* (86.7%, item 9A). The four items on which the P-SSMTs scored the lowest involved *how errors due to sampling affects inferences about a population mean* (13.3%, item 11), *understanding the graphical description (histogram) of a quantitative variable* (20.0%, item 2), and *interpretations of confidence intervals* (26.7%, both item 17B and 17D respectively).

CIiS subscales cores on the pre-test

Table 1 below displays the P-SSMTs pre-test scores on the CIiS seven subscales, and shows that the P-SSMTs were the most successful in items related to *probability* (76,6 % success rate), *issues involving sampling* (71.0% success rate) and the *general logic of making statistical inferences* (67.7% success rate). The areas in which the P-SSMTs struggled the most were *confidence intervals within making statistical inferences* (41.0% success rate), *informal inference* (46.7% success rate) and *distributions* (49.3% success rate), which also is reflected in the success rate of the individual items pointed in previous section.

Subscale (max subscale score)	**Pre (n=30)** % ($\bar{x}$; σ)	**Pre (n=17)** % ($\bar{x}$; σ)	**Post (n=17)** % ($\bar{x}$; σ)
Probability (2)	76.7% (1.53; 0.63)	82.4% (1.65; 0.61)	88.2% (1.71; 0.50)
Distributions (4)	49.3% (1.97; 0.93)	70.2% (2.18; 1.07)	44.0% (1.76 ;1.03)
Sampling (7)	67.1% (4.80; 1.40)	70.6% (4.94; 1.39)	89.1% (6.24; 0.90)
Informal inference (3)	46.7 % (1.40; 0.73)	49.0% (1.47; 0.72)	39.3% (1.18;0.73)
[a]SI: general logic (3)	71.0% (2.13; 0.82)	64.7% (1.94; 0.82)	80.3% (2.41; 0.80)
[a]SI: confidence intervals (6)	41.0% (2.47; 1.38)	51.0% (3.06; 1.30)	59.8% (3.59; 1.73)
[a]SI: p-values (5)	56.6% (2.83; 1.18)	38.8% (1.94; 0.83)	48.3% (2.41; 0.80)

Table 1: P-SSMTs' results on the seven CIiS subscales on the CIiS pre- and post-test. [a]SI is and abbreviation used for *Statistical Inference*.

A pre- and post-test comparison on the CIiS overall scores

Looking at the overall score on the pre- and the post-test for the n=17 P-SSMTs who completed both tests, the P-SSMTs' average scores changed non-significantly (t(16)=0.566, p=0.579) from ($\bar{x}$ = 18.12; σ = 3.18) to ($\bar{x}$ = 19.65; σ = 3.78). The individual score on 18 of the items increased on the post-test, whereas 11 scores decreased and the score on one item stayed the same.

A large gain can be seen on item 6 focusing on *expected patterns in sample variability* were 52.9% of the P-SSMTs who answered incorrectly on the pre-test got the answer right on the post-test (more than doubling the success rate from 35.5% to 76.5%). Also on item 17D (on *confidence intervals*) a large portion (43.8%) of the P-SSMTs who got this wrong on the pre-test answered correctly on the post-test, resulting in an overall increase from 35.3% to 70.1% on the item. Large gains can also be found (see Table 2) for items 17B (*confidence intervals*), 14A, 14B (on *sample size*) and 5 (*sample variability*), and it is notable that the score went up for four of the six items focusing on *confidence intervals*. The gains in item 6, 14B and 17D are all statistically significant on the p=0.05 level.

Among the 11 items on which the score was lower on the post-test compared to the pre-test, is item 11. Item 11 is about *informally rejecting a null-hypothesis*, and the success rate on this item went down from 23.5% to 5.9%. Indeed, 76.5% of the P-SSMTs answered incorrectly on item 11 on both tests. In Table 2 one can also see what portion of the P-SSMTs changed from correct answers on the pre-test to incorrect answers on the post-test (and in this context items 1, 4 (both *describing a distribution*) and 10A (*informal inference using boxplots*) are notable). In addition, one can note that the score for four of the six items focusing on p-values became lower on the post-test. The only statistically significant negative change in score on the p=0.05 level was found for item 1.

A pre- and post-test comparison on the CIiS subscale scores

Table 1 above shows that the P-SSMTs increased their CCK in statistics as measured by the CIiS in five of the seven subscales. The largest gain was done in the subscale *Sampling* (from 70.6% to 89.1%) and in *Statistical inference: general logic* (from 64.7% to 80.3%). However, the P-SSMTs' CCK in statistical went down in the subscales *Distributions* (from 70.2% to 44.0%) and *Informal inference* (from 49.0% to 39.3%). Only the increase measured in the subscale Sampling was statistically significant (t(16)=−3.096, p=0.007).

Discussion

Regarding RQ1 our result shows that the P-SSMTs participating in the study had relatively good CCK in statistics with respect to *probability*, *sampling* and *the general logic of making statistical inferences*, but poorly handled *confidence intervals*, *informal inferences* and *distributions.* The latter is in line with previous research results (Lovett & Lee, 2018) and is perhaps not surprising since neither confidence intervals, informal inferences and distributions normally are part of the P-SSMTs prior educational experiences. The P-SSMTs relative high average score on items related to probability is in line with the result of Nilsson and Lindström (2013) regarding that the participants displayed a basic understanding of the theoretical interpretations of probability. However, the CIiS subscale measuring probability is composed of only two items, and hence only provide an crude and selected snapshot of the participates CCK with respect to probability. It is interesting that p-values, otherwise pointed out as troublesome for P-SSMTs in the research (Lovett & Lee, 2018), not stood out as difficult in the pre-test.

After having participated in the course in statistics, the results show that with respect to RQ2, the P-SSMTs CCK in statistics increased between the pre- and post-test in all areas except those related to *distributions* and *informal inferences*. Although somewhat speculatively, given the limited amount of data, the decrease in the subscale *informal inference* taken together with the increase in the three subscales of *formal statistical inference*, indicate that the course in statistics favor the formal aspects of statistics over more informal ways of making inferences. From a general CCK perspective focusing on the formal aspects of mathematics, this makes sense. However, in light of more recent discussions within the statistics education community, informal inference is suggested to be more important and productive for the teaching and learning statistics (i.e. an important component of so-called *specialized content knowledge* (SCK) to be develop within the MKT- and SKT frameworks). The low scores on the subscale *informal inference* points to the need to provide the P-SSMTs with learning opportunities to develop their informal inference reasoning skills, either in the statistics course, or in an accompanying mathematics education course. In such a (re-)design and development project, a research-based extension of the CIiS scale on informal inference might be a useful tool, which in addition provides interesting research opportunities. In its present form the CIiS only provide a selective snapshot of the CCK in statistics, with a small number of items in each subscale. Hence it is hard to generalize the findings in this study, and the result must rather be interpreted in relation to the particularities of the research settings at hand.

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Appendix: P-SSMTs' results on the pre- and post-test

Item #	$Pre_{n=30}$ % correct	$Pre_{n=17}$ % correct	$Post_{n=17}$ % correct		Item response pattern[a]			
				n	Incorrect (%)	Decrease (%)	Increase (%)	Pre & Post (%)
1	56.7	76.5	47.1	16	18.8	31.3	0	50
2	20.0	29.4	17.6	16	62.5	18.8	12.5	6.3
3	46.7	47.1	58.8	17	23.5	17.6	29.4	29.4
4	73.3	64.7	52.9	16	12.5	31.3	18.8	37.5
5	56.7	64.7	88.2	17	5.9	0	35.3	58.8
6	40.0	35.3	76.5	17	11.8	11.8	52.9	23.7
7	63.3	70.6	76.5	17	11.8	11.8	17.7	58.8
8	90.0	94.1	94.1	17	0	5.9	5.9	88.2
9A	86.7	76.5	94.1	17	0	5.8	23.5	70.6
9B	66.7	58.8	76.5	16	6.3	12.5	31.2	50
10A	63.3	64.7	35.3	15	13.3	46.7	20	20
10B	63.3	58.8	76.5	15	6.7	6.7	26.7	60
11	13.3	23.5	5.9	17	76.5	17.7	0	5.9
12A	83.3	94.1	88.2	17	0	11.8	5.9	82.4
12B	93.3	94.1	94.1	17	0	5.9	5.9	88.2
13	83.3	82.4	88.2	17	0	11.8	17.7	70.6
14A	66.7	64.7	94.1	17	5.9	0	35.3	58.8
14B	56.7	58.8	94.1	17	5.9	0	35.3	58.8
15	83.3	82.4	82.4	17	0	17.7	17.7	64.7
16A	60.0	52.9	64.7	16	18.8	12.5	25	43.8
16B	26.7	29.4	23.5	16	56.3	18.8	18.8	6.3
16C	76.7	88.2	82.4	16	6.3	6.3	6.3	81.3
16D	36.7	35.3	23.5	16	56.3	18.8	12.5	12.5
17A	60.0	58.8	47.1	15	26.7	20	13.3	40
17B	26.7	29.4	52.9	15	33.3	6.7	40	20
17C	36.7	52.9	64.7	15	20	6.7	26.7	46.7
17D	26.7	35.3	70.1	16	25	0	43.8	31.3
18	66,7	82.4	70.1	16	0	25	18.8	56.3
19	30.0	47.1	52.9	16	31.3	12.3	18.8	37.5
20	60.0	58.8	70.6	14	0	21.4	28.6	50

Table 2: P-SSMTs' results on the pre- and post-test. [a]Following DelMas et al. (2007) item response pattern reported are: Incorrect = incorrect on both pre- and post-test; Decrease = correct pre-test, incorrect post-test; Increase = incorrect pre-test, correct post-test; Pre & Post = correct on both pre- and post-test (green indicate an increase; red a decrease).