AN ABSTRACT OF THE DISSERTATION OF

Barbara Ettenauer for the degree of Doctor of Philosophy in Education presented on May 13, 2024

Title: Concept Maps from a Contemporary Perspective

Abstract approved:

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Cory Buxton

This dissertation examined concept maps from a contemporary perspective. As graphic organizers concept maps have traditionally been considered as an effective tool that visually portrays what a person knows about a topic (Chou et al., 2022). Yet, as learning is socio-cultural, and these stimuli were embodied by the learner (NASEM, 2018), this dissertation tested the hypothesis that concept maps actually hold more information, such as language or cultural connections rather than knowledge only. In the first manuscript, which focuses on the application of theory to practice, I used the LaCuKnoS model (Buxton et al., 2022) and LCT autonomy codes (Maton & Howard, 2018) to analyze the knowledge, language, and cultural connections that are embedded in the concept maps. Using examples from one multilingual elementary afterschool science club, the first manuscript argues that

students positioned themselves as competent knowers, used flexible word choices that fitted their communication purpose, and built upon their lived experiences. Yet, even though there were hints to some explicit cultural connections, such as the use of translanguaging or art, there was not enough evidence in the data to support the claim that students' concept maps leverage or build upon such cultural connections. In the second manuscript, which is more focused on the needs of practicing educators, I explore a role for concept maps that better suits our contemporary perspectives on learning. The notion of identity artifacts (Subero et al., 2018) applies well to concept maps as it describes how artifacts show what has meaning for the students, which in turn could be of educational use. Analyzing interviews from ten teachers who worked in eight after school science clubs, as well as self-reflective researcher data, I used Holland et al.'s (1998) figured worlds theory to show that concept maps created multiple figured worlds in which the maps were perceived differently. These findings also highlighted how teacher and researcher could benefit from each other's expertise and create a shared understanding to the students' benefit. Overall, results suggest that concepts maps are identity artifacts that hold more information about students that goes beyond what they know about a topic, but it will require future research to ask more detailed questions in form of students' interviews or think alouds to make a general claim about their cultural connections. Finally, recommendations for educators emphasized the potential value of using concept maps more often in science classrooms and of giving students more agency to be creative and make concept maps their own. It is this opportunity to holistically show understanding, using language(s),

examples, and modalities that have personal meaning that may make concept maps work worth the time and effort they require to create and evaluate.

Concept Maps from a Contemporary Perspective

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Barbara Ettenauer, Author

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It was Confucius who said, ‘It does not matter how slowly you walk as long as you do not stop.’ Yes, so true. This was quite a journey with ups and downs but the people I met along the way made all the difference.

First, I like to thank my advisor, Dr. Cory Buxton who from the beginning supported my wish to become a researcher of science education. He always encouraged me to think outside the box but made sure that it is not too overwhelming for me at the same time. He never pushed or forced anything. Instead, I was free to get things done at my own pace.

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Finally, I like to thank the participants of my study – the students, who created the concept maps and as such build the heart of this dissertation. Additionally, my thanks goes to the teachers who were willing to make time in their already busy schedule to share their expertise about concept maps.

I usually am not a person who uses a lot of words to express gratitude. So here is a simple but grateful – DANKE!

CONTRIBUTION OF AUTHORS

This dissertation is a sub-study of a multifaceted research and development project called Language, Culture and Knowledge building through Science, or LaCuKnoS. This study emerged from that project and sets the stage for future work to examine change in teacher's understanding about and practices with concept maps.

Dr. Buxton is the principal investor of this NSF funded research project. He helped to develop three holistic rubrics to score concept maps for knowledge, language, and cultural connections and functioned as second evaluator to ensure inter-rater reliability. He also consulted on the interview guide, provided ongoing feedback, and assisted in the editing of the manuscripts and compilation of the dissertation.

Jingtian Yu, a doctoral student, and Dr. Yanming Di, a faculty member, both from the OSU statistics department and members of the LaCuKnoS project, advised on what information should be included when setting up concept maps in excel to facilitate statistical analysis and supported the work with heatmaps.

Undergraduate media student Taylor Pike, who is also on the LaCuKnoS team, helped integrate images into the two-in-one visuals.

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DEDICATION

Danke Eliot! Du bist stets mein Fels in der Brandung.

1. Introduction

1.1 Motivation

Although teacher participants of this study reported that concept maps[1] are not used much these days, they have a long tradition in science education (Quinn et al., 2003). These graphic organizers were first introduced by Novak (1998) in the 1970s and are primarily considered an effective tool for determining what a person knows about a topic (Chou et al., 2022). However, given theoretical shifts in research on learning (National Academies of Sciences, Engineering, and Medicine [NASEM], 2018) that now views learning as social and cultural, and that the learner embodies these stimuli, this traditional view of concept maps no longer seems adequate. Thus, it is argued, that maps hold more information than just what a person knows conceptually and cognitively about a topic. In fact, chosen concepts and labeled links are word choices, which suit the constructor's communication purposes and at the same time hint to what is meaningful to that person.

In the context of science education, this new perspective of concept maps has implications for how, for example, teachers view their students work, which in turn can help optimize their teaching. Assuming that concept maps are constructed by students in a school setting, they can be considered what Subero et al. (2018) define as identity artifacts, because they show what is meaningful for students, while being of educational use at the same time. This contemporary expression seems more suitable rather than using the term cultural artifacts, because in today's multicultural

[1] For a glossary of key terms that are used throughout this dissertation see Appendix A.

societies culture is more fluid and as such just one element that makes up a person's identity (Davidson, 1996). Thus, acknowledging the contemporary perspectives of concept maps, meaning that they are multilayered and provide information about the student's identity, could be helpful for teachers to build on existing strengths and skills students bring to the classroom.

Nevertheless, it is in the nature of things that people perceive artifacts differently (Holland et al., 1998). A report card, as an example of a tangible artifact, provides information about a student's progress in school but might evoke different emotions in caregivers than in students. The same will be true if teachers and researchers evaluate the same concept maps. In some instances, their narratives might overlap, elicit inside information, or point to blind spots but overall may cause them to position students based on their work sample. This does not always happen to the student's advantage, especially when positioning is influenced by representations or fictional images about the learner (Harklau, 2000) rather than as the result of analysis. Thus, this study aims to demonstrate the value of a contemporary approach to analyzing concept maps and how the expertise of teachers and researchers potentially create a shared understanding so that students' work can be viewed from a more asset-based perspective.

1.2 Overview

This study examined student-generated concept maps, teacher interviews, and researcher documents to reveal student's knowledge, language, and cultural science sense making, and to describe how teachers and researchers could profit from each other's expertise for the benefit of the students. Data was mainly collected through a

bigger research project called LaCuKnoS short for Language, Culture, and Knowledge building through Science. Data collection and analysis for this sub-study happened between April 2022 and February 2024.

For the purpose of this dissertation, two articles were designed that build on each other. The first one was set up (a) to examine whether concept maps, which are highlighted as a tool that supports diverse learners (Marzetta et al., 2018), actually contain more information than what a student knows about a topic, and (b) to test the feasibility of Legitimation Code Theory (LCT) autonomy codes for multiple purposes. The second article addressed the question of how findings from the first paper can be helpful for teachers in optimizing teaching and learning in science education.

Above all, especially the concept maps analysis brought with it some challenges as new terrain was developed. These will therefore be discussed in more detail next before I will briefly describe the two articles.

1.2.1 Concept Map Analysis

Concept maps for this study were collected through a bigger research project called LaCuKnoS who works closely together with a longstanding pre-college program for K-12 students. In April 2022 this pre-college program organized a challenge, which was held at local schools across the Pacific Northwest due to COVID-19. The concept map activity was a pre-cursor activity into the topic of community food innovations resulting from food insecurity caused by natural disasters. A total of 20 after school science clubs participated and turned in 195 concept maps. The analysis process took place in several phases.

First, I had to come up with an approach for how to transfer the information from the concept maps into a spreadsheet for organization and analysis. Additionally, a holistic rubric, which is called translation device[2] in LCT language, was created to score propositions for knowledge, language, and cultural connections. In September 2022, I started setting up the excel files[3] for each student at the club level[4] and began scoring the nearly 2000 propositions extracted from the 195 maps. During the entire time of the analysis process, I was in contact with the PI of the research project to clarify uncertainties. The PI also functioned as second evaluator to ensure inter-rater reliability. Additionally, I developed a codebook[5] to capture rules that were agreed on whilst setting up the concept maps, such as determining that propositions with a missing second concept were defined as hanging links.

In this phase, I encountered drifts in scoring that occurred due to the fine-tuning processes of working with the LCT translation device over time. I found that I frequently had to go back and check the knowledge scoring for already scored maps. Thus, I created a 'dictionary'[6] to ensure that scoring was consistent within and across clubs. Finally, in July 2023 all concept maps were scored for knowledge, but the other two strands were still missing. Thus, already in spring 2023 it became clearer

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[2] Appendix B shows the translation device for all three strands.

[3] Appendix C shows a screenshot how maps were set up in excel.

[4] Appendix D has a timeline when clubs were scored for knowledge.

[5] Appendix E shows a screenshot of the codebook that was set up over time.

[6] Appendix F displays a screenshot of the dictionary for knowledge.

that I needed to decide how to proceed with the work for this dissertation because the scoring process was unexpectedly time intense, and it would take years to finish scoring of all maps just from the 2022 challenge.

Thus, I decided to focus on one multilingual elementary club where I helped facilitating the concept map activity in April 2022. This decision was guided by Marzetta et al., (2018) who found that maps are a tool that supports diverse learners but also mentioned that concept map research with younger students is rare. I also wanted to do an in-depth analysis that could provide guidance to the rest of the LaCuKnoS team for how to proceed with the bigger data set. I also thought deeply about what value there is in LCT analysis, but which also presented some challenges. For example, as I had no time stamps that explained which concept came first and which one next, I could not show autonomy tours on the coordinate plane as other researchers using LCT would normally do. Additionally, scores that were placed on the coordinate plane reduced the richness of the multimodal student maps to numbers.

Yet, in May 2023 when I participated in another challenge that the pre-college program organized, which aimed to use art to portray scientific data (Fleishman, 2023) I felt encouraged to come up with creative ideas to display my data. For example, with the help with some of the LaCuKnoS members a poem[7] was written that described the process of LCT analysis. Another idea aroused when I was looking at a collage, was to add symbols into the two-in-one visuals. Additionally, conversations with peers and mentors, whom I met during a PhD retreat in South

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[7] See Appendix G.

Carolina, encouraged me to come up with student profiles that described patterns that I saw in the two-in-one visuals.

Thus, I started sorting the two-in-one visuals for the Curious Minds club, a pseudonym for the multilingual elementary club, which I chose for the first article. This process enabled me to come up with rules[8] that described the student profiles. Next, in order to test if the rules also apply to other clubs, I completely scored the concept maps from two more clubs – one each for middle, and high school resulting in adding another rule that came up from the data. I also thought of other ways how to present LCT autonomy codes on the coordinate plane to highlight the value of coding, such as what I refer to in paper one as the three-strand tour. By the end of summer of 2023, I was done with the in-depth analysis for manuscript one and started writing up the findings.

As far as the second article is concerned, only those teachers who participated in the 2022 challenge and were willing to have a short discussion about concept maps were interviewed. Ten teachers from eight clubs participated in follow-up interviews and at the same time decided through their participation which clubs needed to be analyzed next. Thus, I scored these eight clubs between November 2023 and January 2024 for language and culture, as I needed these data to be able to compare and contrast the teachers and researchers' perspectives on concept maps as well as to come up with patterns within and across clubs.

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[8] See Appendix H for the rules and Appendix I how to interpret them.

1.2.2 Article One

This mixed methods study, which is titled *Healthy Candy Canes and Magic Ramen: Do Concept Maps Show Knowledge, Language and Cultural Connections?* was conducted to answer the following research question: How do elementary students' concept maps from a multilingual after school science club reflect their sense making during a science lesson in ways that support students' (a) science knowledge building for informed decision making; (b) language development for science communication; and (c) cultural and community connections to science.

Two theoretical frameworks were used, which acknowledge the contemporary perspective of concept maps. (a) The LaCuKnoS model (Buxton et al., 2022) is an instructional approach for multilingual science sense making that allowed me to examine concept maps through a sociocultural lens. (b) Autonomy is one dimension of LCT, which is a multi-dimensional framework first introduced by Karl Maton (2013) that reveals shifts in knowledge practices. This framework was helpful to analyze maps using multiple targets. 13 concept maps from one multilingual elementary science club were chosen because it fulfilled criteria to answer the research question.

Findings showed that students took ownership ensuring that what they learned was responsive to their needs and what they wanted to share about themselves and their ideas through their concept maps. Overall, this study emphasizes that concept maps actually hold more information than conceptual knowledge, such as information about flexible word choices that suited the students' communication purposes or had concepts that pointed to personal experiences. However, even if there was evidence

that hinted to explicit cultural connections, such as drawings or the use of translanguaging, more data is needed in order to make meaningful claims for cultural connections.

1.2.3 Article Two

This qualitative paper is titled *'What is the point of doing this?': How Teachers and Researchers Create Figured Worlds of Concept Mapping* and was conducted to answer the following research question: How does thinking about concept maps help teachers figure about supporting their student's science sense-making? Although the findings of the first study were promising, they did not quite succeed in showing connections to all three strands, which made it even more important for me to apply a term for concept maps that better describes their contemporary purpose. Thus, this study explains that concept maps meet the criteria to qualify as identity artifacts (Subero et al., 2018), because the information embedded in the maps is meaningful to the student and of educational use.

Holland et al.'s (1998) figured world theory was used to describe how concept maps in their role as identity artifacts created and crossed two as-if worlds – the one of the teachers and the other of the researchers. Data that speaks to the teachers figured world included ten teacher interviews from eight after school science clubs who participated in the April 2022 challenge. Teacher interviews were conducted between June and October 2022. Additionally, data that speaks to the researchers' figured world, such as analyzed concept maps, heatmaps, student profiles, memos, and recordings of meetings was collected between April 2022 and February 2024.

This study highlights that even though concept maps were perceived differently between and within figured worlds, through cooperation with others they have the potential to change people's perspective and therefore create new worlds full of possibilities for the benefit of the students.

1.3 Theoretical Framework

This study used multiple frameworks that guided the analysis. The first article applied the LaCuKnoS model (Buxton et al., 2022) and LCT autonomy codes (Maton & Howard, 2018, 2020) to study concept maps in a new way. The LaCuKnoS model is an asset-based framework that brings together theoretical tools, such as Halliday's (2004) systemic functional linguistics (SFL) and culturally sustaining pedagogy (Paris, 2012). Differently, LCT autonomy codes visually show the relationship between content and purpose of a learning interaction on a coordinate plane, called the autonomy plane (Maton & Howard, 2018, 2020). As such concept maps propositions are scored using a holistic rubric, known as a translation device amongst LCT researchers, that does not create the usual poor, better, or best hierarchies.

The second article used Holland et al.'s (1998) figured worlds theory to analyze teacher interviews and researcher documents. This theory builds on the premise that people create dynamic 'realms of interpretation' (Holland et al., 1998, p. 52) through their day-to-day activities, which force them to find their role and to position themselves and others in these systems. One example for a figured world is Alcoholics Anonymous (AA), a self-help organization for people who abuse alcohol where artifacts like poker chips have a special meaning (Holland et al., 1998). Even if this theory is a bit vague and inconsistently used in the literature (Urrieta, 2007), it is

a powerful approach that opens up the possibility that these systems can change any time through people's day-to-day activities no matter how small they are.

1.4 Positionality

My perspective, as a feminist, middle-class, female doctoral candidate, former special education, and self-employed science teacher, educated in Europe and in the U.S., afforded me a variety of lenses with which to view education. As a developing scholar, my primary interest is to provide equal learning opportunities for all students. I truly want to make a difference in science education for the student's benefit. Coming into this project, considering reality subjectively and holding a pragmatic worldview enabled me to "use all approaches available to understand the problem" (Creswell, 2018, p. 10). Yet, it is inevitable that my own background affected the data collection and the study design in some ways.

In order to overcome biases, an internal and external approach was applied to warrant trustworthiness. Externally, the larger research project pursued three strategies to increase chances that findings are credible (Lincoln & Guba, 1985; Maxwell, 2013). (a) Prolonged engagement by being already an active part of the LaCuKnoS research team since the beginning, enabled me to get a better understanding of the setting and the participants. (b) Detailed data collection methods, such as surveys, transcribed family and teacher focus group interviews done over time enabled with the generation of "rich data" (Maxwell, 2013, p. 126) that is detailed enough to know what is going on. (c) Finally, methodological and researcher triangulation enabled a thorough evaluation of the collected data.

Internally, in regard of the concept map analysis, I worked closely together with the PI of the LaCuKnoS project, which allowed me to ask for feedback or clarifying questions whenever needed. I started scoring the propositions and the PI reviewed them. In case of disagreement, we discussed these incidents until 100% agreement was reached (American Educational Research Association, American Psychological Association, & National Council on Measurement in Education, 2014). As narratives have not just one reality and words can easily be mistaken, I was careful with the interpretation of narratives and tried to focus thoroughly on what was said. Overall, reflective practice (e.g., ask for feedback in different phases of the project) or writing memos helped to capture my thoughts and insights.

1.5 Significance

The outcome of the two studies provides insights for educators and researchers. The first article emphasized the argument that concept maps are multilayered and offered a new framework in supporting all, but especially diverse students with the conceptual and linguistic practices and skills they will need in their future. It also adds to the research on LCT Autonomy as it demonstrated that thoughts need to travel into and through multiple quadrants of the autonomy plane depending on what is helpful to the learner. Yet, even if autonomy codes are useful for multiple targets, not all topics, such as culture, are probably a good fit for LCT Autonomy analysis.

The second article highlighted that concept maps are best described by using the contemporary phrase identity artifact rather than cultural artifact because in today's multicultural societies, culture is just one part that makes up a person's

identity (Davidson, 1996). As such, concept maps have double meaning because they demonstrate what has significance for the student and are of educational use. As this study showed that artifacts are perceived differently within and between figured worlds (Holland et al., 1998) it was recommended to rely on solid analysis rather than visual observation only when evaluating maps. To achieve the best possible outcome for the students, it would be ideal, although not always possible in reality, if educators and researchers collaborate to create a shared understanding.

1.6 Limitations

There are limitations that come with this study. Although discussed in each article, three of them should be emphasized here. (a) Probably one of the major limitations of this study is that the student's voice is only represented through their concept maps, which left room for misinterpretations. Studies that use student interviews or think alouds would provide a deeper insight into the student's thinking and enrich this area of research. (b) Additionally, using LCT autonomy codes was unexpectedly time and labor intense. Therefore, it seems unlikely that teachers would be able to find the time to analyze concept maps using this theoretical approach. Thus, automation of the scoring process would be extremely helpful and might be a topic for future research, especially given recent advances in applications of artificial intelligence. (c) Finally, having a teacher as co-author would be especially beneficial for the second article, as I had two roles to fulfill – that of the storyteller and the researcher. Yet, again, it is not always possible for teachers to take on these additional jobs due to their already busy school day. Thus, moving forward in the larger project

it is considered to share parts of the concept maps analysis with the teachers and ask for feedback.

1.7 Organization

This manuscript dissertation analyzes concept maps from a contemporary perspective. The first article as presented in the second chapter, examines if concept maps contain knowledge, language, and cultural-related information about the learner, using the example of a multilingual elementary after school science club. It also tests the feasibility of LCT autonomy codes for multiple purposes. The second article as presented in chapter three describes how concept maps were perceived differently by educators and researchers and discusses how findings from the first paper can actually be helpful for teachers and researchers. Finally, in the fourth chapter, findings are compared and discussed, thoughts on the theoretical frameworks were shared and recommendations are made.

2. Healthy Candy Canes and Magic Ramen: Do Concept Maps Show Knowledge, Language and Cultural Connections?

2.1 Abstract

Concept maps are used for teaching, studying or assessment in science education. Yet besides showing connections to what a person knows about a topic, they also display which language choices were helpful for the learner, and hint at personal experiences that are embedded in the maps. This mixed methods study uses concept maps from an elementary multilingual after school science classroom to show how students used the full range of available resources to communicate their scientific ideas. Two theoretical frameworks were applied. First, the LaCuKnoS model as an instructional approach for multilingual science sense making was helpful to study maps from a contemporary perspective. Second, LCT Autonomy allowed a focus on multiple targets to score maps holistically for various purposes. Findings showed that students positioned themselves as competent knowers, made flexible language choices and incorporated personal experiences when constructing their maps. This study also adds to the literature on LCT Autonomy because in contrast to focusing on effective instruction, where the teacher ideally starts and ends their instruction conceptually 'on target', students' thoughts journey into and through multiple ideas. This new application of LCT Autonomy highlights what was helpful for the learner to both understand and make personal connections to the target and content.

Keywords: Science Education; Concept Maps; Legitimation Code Theory (LCT)

2.2 Introduction

The nearly two years of remote learning due to COVID-19 have had a significant impact on all but especially marginalized students, such as multilingual learners (Ehren et al., 2021) who speak multiple languages other than the language of instruction at school (Buxton & Lee, 2023). The U.S. Department of Education's Office for Civil Rights (2021) reported that 'for many English learners, the abrupt shift to learning from home amid the challenges of the pandemic has made that struggle even harder' (p. iv). Thus, these demanding times added to existing educational disadvantages multilingual learners were already confronted with (Ettenauer et al., 2023b). Yet, these are also challenging conditions for teachers to establish high quality education for all (Gitschthaler et al., 2022), which aims among other things to integrate what has significance for the students, such as their interests or culture to make learning more meaningful for them.

In order to meet these demands practical tools are needed to determine what assets teachers can build on while at the same time giving diverse learners the opportunity to demonstrate what is important for them. Marzetta et al. (2018), for example, suggested that concept maps 'are one way to validate the diversity of learners and the cultural spaces they are situated' (p. 3) in. These graphic organizers have a long tradition in science education and have mainly been used for teaching or assessment at school (Quinn et al., 2003) because they visually show the relationship between concepts (Oliver, 2009). While concept maps might not be ideal for all learners (Marzetta et al., 2018), they certainly support those who like to draw on skills, such as using translanguaging (Jakobsson et al., 2021) or drawings to express

thoughts. Students who know how to construct concept maps, can easily take ownership of them because there is no right or wrong to it other than any constraints put in place by the teacher.

Traditionally concept maps have been recognized as an effective tool that reveals what a person knows about a topic (Chou et al., 2022). Yet, given our current understandings that learning is socio-cultural and that the learner in turn, expresses their contextualized learning in many ways, such as through language or writing (National Academies of Sciences, Engineering, and Medicine [NASEM], 2018) one might wonder if concept maps as student's artifacts mirror these impacts. For example, researchers like Mantei and Kervin (2014) studied artwork student created after they read a picture book and found that the collages linked to personal experiences. Still others (Marzetta et al., 2018) mentioned that concept maps display personal experiences that were made outside of school. Applying these contemporary perspectives to concept maps, one might consider that they are multifaceted and as such could display connections to student's knowledge, language, and cultural understanding. Therefore, one purpose of this study was to examine whether this hypothesis is supported by data.

Coming into this project as a multilingual learner who had worked with elementary students as a freelance science teacher in Europe for over 10 years, I was especially interested how younger multilingual students use concept maps to show others, such as teachers or researchers, what is important to them. Thus, it was fortunate that I was involved in a research project called LaCuKnoS (Buxton et al., 2022), short for language, culture, and knowledge building through science that used

concept maps as a research instrument. This NSF funded project uses an instructional approach for multilingual science sense making and supports teachers in enacting contemporary practices for science learning while studying how educators in after school science clubs take up these practices. Moreover, knowing that research, which focuses on concept maps as a multifaceted tool that supports multilingual elementary students is scarce (Marzetta et al., 2018), this study aims to close that gap.

The overall goal of this paper was twofold. (a) It aimed to examine if concept maps actually uncover knowledge, language, and cultural connections, and (b) it tested the feasibility of Legitimation Code Theory (LCT) autonomy codes to assess concept maps for multiple purposes. Thus, this study, which is framed around 13 elementary students from a multilingual after-school science club in the U.S., contributes to the research on concept maps as it describes how these students incorporated word choices, hinted to personal interests, and used what they know to position them as competent knowers. As such, this paper aims to answer the following research question: How do elementary students' concept maps from a multilingual after school science club reflect their sense making during a science lesson in ways that support students' (a) science knowledge building for informed decision making; (b) language development for science communication; and (c) cultural and community connections to science.

2.3 Literature Review

2.3.1 What are Concept Maps?

Concept maps are graphic organizers that present multiple relationships between concepts (Oliver, 2009). As such they visually illustrate what a person

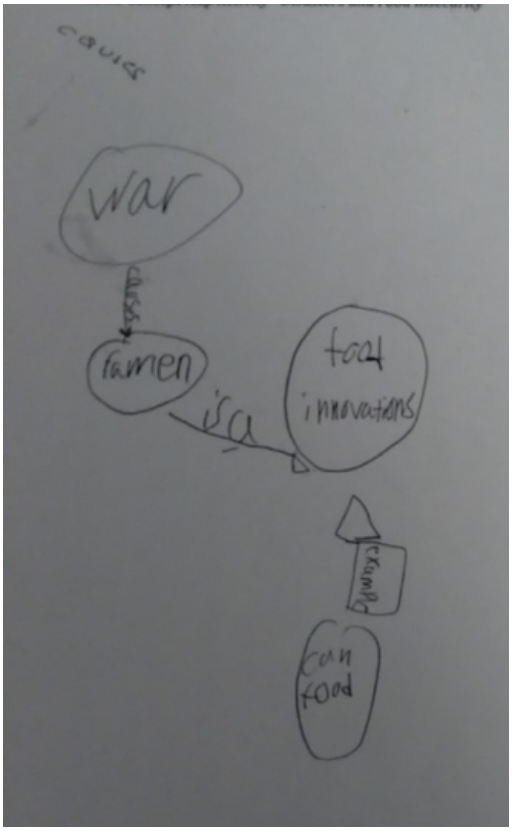
knows about a topic. They were first introduced by Novak (1998) and his research team in the 1970s building on Ausubel's assimilation theory, which describes meaningful learning as a combination of what a learner already knows, the use of relevant learning material, and the learner's wish to learn.

Maps consist of several parts (see Figure 2.1). There are concepts or nodes, which are typically drawn as circles or boxes using mostly nouns as descriptors, such as the concept 'war'. Two concepts are linked by lines or arrows, which are labelled with a word or phrase that clarifies the relationship between them. A pair of concepts including the labeled link is called proposition, which almost reads like a simplified sentence (Zak & Munson, 2008), such as the proposition 'ramen is a food innovation.'

The graphic organizers can be drawn with pencil and paper, or using computer software, such as Cmap or Inspiration. Usually, people are given a specific prompt when asked to construct a map (Novak, 1998). These pre-given conditions range from complete independence where any topic can be chosen to no choice at all when individuals are asked to memorize an expert map. Thus, it is good to keep in mind that the number and nature of restrictions influence the quality of a concept map.

Figure 2.1

Angel's Concept Map



2.3.2 Usage in Science Education

Concept maps are used for instruction, assessment or as a research instrument in education. As an instructional tool, they visually break down topics in manageable parts to make them more transparent, such as during reading comprehension (Oliver, 2009). They are an effective learning instrument that can increase the learner's motivation (Chou et al., 2022). Since the general focus is on conceptual relations rather than providing the right answer, concept map activities encourage students to think outside the box and create equitable learning opportunities for diverse learners (Marzetta et al., 2018).

Usually considered a flexible assessment tool (Reiska et al., 2018) to measure knowledge, concept maps provide teachers with additional information about how students remember, organize, and how they understand a subject (Zak & Munson, 2008). For example, concept maps pointed to weaknesses of a program for engineering students (Besterfield-Sacre et al., 2004), revealed concepts which were omitted by preservice teachers teaching ecology (Zak & Munson, 2008), and offered information on which concepts were recalled after six months of instruction (Quinn et al., 2003). Even though they provide valuable insights, concept map scoring takes more time compared to multiple choice tests where scoring can be easily automated (Quinn et al., 2003; Reiska et al., 2018). Another limitation that has been raised is that concept maps do not provide information about the learner's cognitive style because what a person knows and the way a person thinks, and solve problems are somewhat different (Jablokow et al., 2015).

Finally, like in this study, concept maps are often used as research instruments. They function as a tool to collect data from participants which may be analyzed and used in various ways. For example, Watson et al. (2016), who studied effects on conceptual knowledge by analyzing concept maps that focused on sustainability, found that each scoring method has strengths and weaknesses. Others (Reiska et al., 2018) studied interdisciplinary learning in Estonian high schools by comparing concept maps with a PISA like test and found that scoring can be time consuming if evaluators share different opinions of how to score them. They concluded that researchers must be careful when comparing concept maps that have been constructed under different conditions as the maps will reflect these differences.

2.3.3 Analysis Methods

Several methods have been used to analyze concept maps (Ries et al., 2021). (a) The more traditional quantitative approach counts characteristics of maps, such as numbers of concepts and links, but this approach has been critiqued because frequency counts, when taken alone, do not relate to the quality of the content seen in the maps (Besterfield-Sacre, et al., 2004). (b) Qualitative scoring focuses on describing the characteristics of concept maps, such as which terms were used, which is known as semantic sophistication (Ries et al., 2021). (c) The similarity approach compares student maps with an expert map to check if the learning as displayed on the map was conceptually correct and how much was learned (Jablokow et al., 2015). (d) Holistic analysis, which is applied to this study, uses a rubric that evaluate maps using a poor, better, or best hierarchy. For example, Borrego et al. (2009) designed a rubric focusing on comprehensiveness, accuracy, and concept arrangement. However, some researchers (Cardozo-Gaibisso et al., 2019) questioned if numbers alone provide researchers with useful insights, as they do not allow a thorough feedback about the richness found in artifacts. (e) Finally, some scholars used what this research team calls a mixed approach by combining two or more methods when doing their analysis. For example, Besterfield-Sacre et al. (2004) used a rubric and quantitively counted concepts, hierarchies, and cross links.

2.3.4 Concept Maps and Multilingual Elementary Students

Most of the studies cited in this literature review used concept maps that were constructed by secondary students and older. Just three papers focused on younger learners and mostly attended to the idea of concept maps as a learning tool, with only

one of these focusing on diversity. Chou et al. (2022), for example, studied the effect of concept maps on digital science learning in a third grade Taiwanese classroom and found that concept maps can improve the learner's motivation. Whereas the Giovani team (2008) found that a card game as a pre-practice activity helped fifth grade students who were new to concept mapping to come up with complex maps. Only Marzetta et al. (2018) studied the impact of concept maps on diverse learners, namely gifted or talented students and English Language Acquisition (ELA) students, who did not speak English well or at all. Findings showed no statistically significance between the groups, causing researchers to conclude that concepts maps promote elementary science learning among diverse learners and by doing so 'create equitable learning opportunities.' (Marzetta et al., 2018, p. 10). In addition to the fact that studies with younger learners who are multilingual using concept maps are scarce, researchers usually studied the impact of concept maps on conceptual understanding, but language and cultural connections as displayed in the maps were overlooked. The current study uses a mixed approach to analyze elementary grade students concept maps in ways that address those limitations.

2.4 Theoretical Framework

This study is influenced by the LaCuKnoS model, which was helpful to examine concept maps from a sociocultural perspective and LCT autonomy codes that allowed using multiple targets to examine data.

2.4.1 The LaCuKnoS Model

The LaCuKnoS model is an instructional model for multilingual science sense making that builds on the premise that language, culture, and knowledge are

interwoven and influence students' science sense making (Buxton et al., 2022). This asset-based framework highlights co-construction of understanding with the participants and brings together theoretical tools that help examine concept maps from a contemporary perspective.

The model builds on three theories that guide the strands. 'La' stands for language development for science communication and supports students in making flexible language choices that fits their purposes when presenting themselves and what they know to a particular audience. This strand builds on Halliday's (2004) systemic functional linguistics (SFL), a language theory that discusses how talk is shaped by people's experiences and learned through doing.

'Cu' stands for culture and community connections to science and aims to strengthen students' science interests and encourages them to bring in their culture, community, personal and family histories during science lessons. This strand extends culturally sustaining pedagogy (CSP; Paris, 2012), an approach that both honors and intentionally supports students' cultural and linguistic diversity. The culture strand of the LaCuKnoS model also recognizes how learners apply school learning in their home and community to create new meaning in connection to their interests. As such, schools strive to maintain and foster students' and families' ways of knowing rather than leaving individual cultures behind.

Finally, 'Kn' stands for knowledge building for informed decision-making and aims to support students by helping them to position themselves as competent knowers. This strand applies LCT (Maton, 2013), a sociological framework for understanding knowledge practices. Lessons developed in this project encourage

students to apply evidence to their daily decisions and to propose solutions to community challenges because they should experience how science knowledge is built and accepted through social problem-solving tasks that have relevance to their lives.

2.4.2 LCT

This multi-dimensional framework aims to reveal shifts in knowledge practices. It was first introduced by Karl Maton (2013) and builds on Basil Bernstein's theory of language codes, which analyses social class inequalities displayed in language. It also draws on work from Pierre Bourdieu who looked at the dynamics of power in society. Thus, legitimation deals with questions like who gets to decide or has the power to have ideas and language viewed by others as appropriate within a given context (Flores & Rosa, 2015). Typically, LCT represents ideas graphically using coordinate planes to portray various conceptual dimensions, such as Specialization[9], Semantics[10] or Autonomy. The latter is used for this study.

2.4.2.1 LCT Autonomy. LCT autonomy codes portray the relationship between the content and purpose of a learning interaction (Maton & Howard, 2018, 2020). Like the other dimensions of LCT, autonomy codes are used to analyze ideas in terms of two targets. In this case targets are referred to as positional autonomy and

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[9] Specialization explains the relationship between epistemic knowledge and who is the knower.

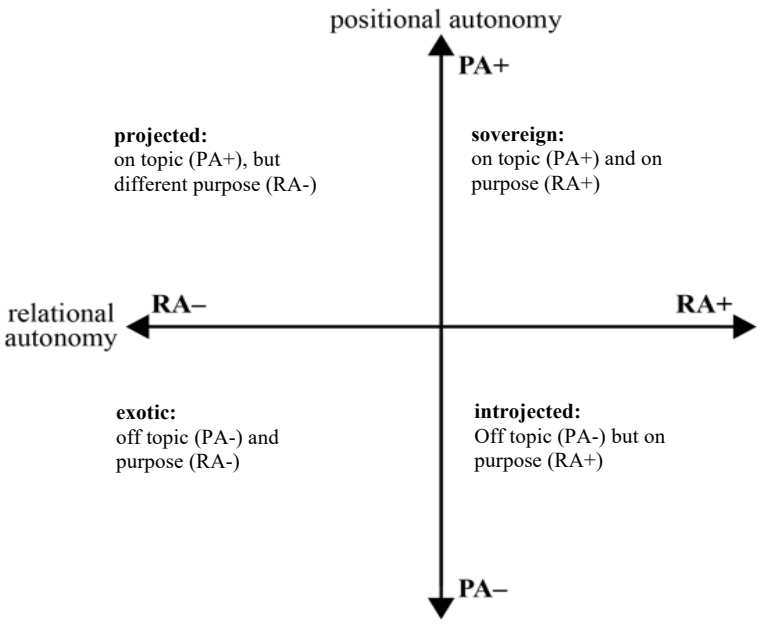
[10] Semantics describes how context dependence and complexity are woven together and practiced linguistically.

relational autonomy. The way content is positioned in an educational context, known as positional autonomy (PA), refers to what is taught, such as the topic of a concept map activity. The purpose for why that content is meant to be learned, known as relational autonomy (RA), refers to how the purpose was taught or expressed, such as preparing students to pass a test or to engage in some activity.

In LCT autonomy analysis, targets for content and purpose are typically determined by the researcher to study the available data in terms of their relations to those targets. A translation device, that functions as a type of holistic rubric, connects the actual data to the concepts of PA and RA by determining how strongly or loosely connected statements are to the target. The various PA, RA combinations are then placed on an autonomy plane (see Figure 2.2). PA and/or RA are considered 'autonomous or strong' when close to the target and can be found in the plus quadrants of the coordinate plane. Whereas if PA and/or RA are further away from the target they are called 'heteronomous or weak' and placed in the minus quadrants (Maton & Howard, 2018, 2020).

Figure 2.2

LCT Autonomy Plane



Note. From Howard & Maton (2020), adapted by author (2023).

Figure 2.2 shows the four quadrants of the autonomy plane, which all have different meanings. For example, imagine that a class learns about how ice cream is made during science class. Talking about thermodynamics would be considered sovereign (PA+, RA+) in this example, as both the PA and RA remains on point for understanding how ice cream is made. Talking about an upcoming school field trip to the zoo would be exotic (PA-, RA-) because it seems completely unrelated to the topic of how ice cream is made. Doing an experiment with hot and cold-water interactions would be introjected (PA-, RA+) because PA is about a different topic (not ice cream), but the purpose is helpful to understand the concept of how ice cream is made. Telling a joke, such as “I scream, you scream, we all scream for ice cream” would be considered projected (PA+, RA-), because the joke was about the topic (ice

cream), but the purpose was to make students laugh rather than to understand something about how ice cream is made.

Finally, if available based on how data was collected, tracking the temporal dimension of the order in which the ideas represented by the concept map were constructed can help explain which PA, RA combination came first and which next. These points can be numbered and connected in the autonomy plane. Shifts from one quadrant into another are then visually presented as pathways, called autonomy tours. Thus, autonomy code analysis is helpful to see that each of the above examples can support students to achieve the learning outcomes, but only if they are used thoughtfully to guide students to the desired content and purpose. Thus, scholars who have used LCT Autonomy have generally claimed that effective instruction needs to start 'on target' (in the sovereign quadrant) and end up back on target but that it may (and often must) make trips away from that quadrant to help the learner both understand and make more personal connections to that target content and purpose.

2.4.2.2 LCT Autonomy and Concept Maps. LCT Autonomy codes have been applied to data that uses more words than are typically found in concept maps. For example, some researchers studied essays from an U.S. critical literacy middle school class (Jackson, 2021), others analyzed video transcripts from a Chinese foreign language teaching contest (Zhao, 2023) and still others focused on lesson plans for cytology (Mouton, 2021). Additionally, researchers primarily attended to knowledge practices common in a given educational context of interest, such as vocational education in South Africa (Garraway & Reddy, 2017) and Australia (Locke & Maton, 2019). Thus, the application of autonomy codes to student concept

maps in this study, with a perspective on multiple targets that extend beyond knowledge practices, provided an opportunity to explore the feasibility of this analytical approach to a kind of multimodal student work sample that is more typical of contemporary science education.

2.5 Methods

This mixed methods study used data from the LaCuKnoS project to study concept maps. Overall, a total of 20 after school science clubs who turned in 195 concept maps participated in the project during April 2022. The maps used for this sub-study were constructed by 13 elementary students from one of these clubs. The LaCuKnoS model guided the concept maps analysis from a sociocultural perspective and LCT autonomy codes allowed using a holistic approach to score propositions that did not allocate the students' performance into a poor, better, or best hierarchy. Quantitatively, heatmaps are used to show frequency counts of PA, RA combinations in the autonomy plane.

2.5.1 Setting and Participants

A total of 20 after school science clubs in the Pacific Northwest decided to participate in a challenge event that took place in April 2022 and turned in 195 concept maps. These annual challenge events are typically in person activities that bring multiple STEM clubs together at a college or university campus to jointly engage in problem solving activities. During 2022, however, due to ongoing pandemic restrictions, the event took place separately at each local school instead. Seven of the participating clubs were at the elementary level. While the concept maps from all 20 clubs will be analyzed using LCT Autonomy as described above, one club

was chosen as the focus for this paper as it fulfilled all criteria to answer the research question.

This club, which is referred to as ‘Curious Minds Club’, is geographically situated at a K-5 dual language school that has a predominately Hispanic/Latino student population (Oregon Department of Education [ODE], 2023). Concept maps from this club showed a variety of interesting features (e.g., the use of Spanish language, drawings using colors). Additionally, this researcher had a chance to visit the club during the concept map activity. 13 students from the Curious Minds Club participated in this study. Six were females, four males and three students declined to provide gender information. As far as student demographics nine students identified as Hispanic or Latino, one student identified as Hispanic or Latino and Native Hawaiian or Other Pacific Islander, and three students declined to provide race information.

In the broader study, informed consent was obtained from the teacher participants and parents/guardians were sent an opt-out consent form that they completed at the start of the school year. Only a small number of students (<1%) had parents opt out. Pseudonyms were developed to protect the confidentiality of the participants and school.

2.5.2 Data Collection

Concept maps were constructed as part of the 2022 club challenge that focused on community food innovations (CFI) in response to natural disasters that can cause food insecurity. The club read the book ‘Magic Ramen’ (Wang & Urbanowicz, 2019) followed by a discussion about food innovation and food

insecurity. The structure of the concept mapping activity was somewhat restricted by the initial reading and a list of ideas for concepts and linking phrases, designed for those students who got stuck when asked to construct their map from scratch. As almost all students in the club were new to the idea of concept mapping, a handwritten concept map constructed by the visiting researcher was shown to the students to explain its general structure. The teacher and the visiting researcher helped students create their maps when they asked for support on how to bring their ideas to life on paper. Logistically, it was not possible to record for each student the order in which the concepts were written down or do follow-up interviews with the students.

2.5.3 Data Analysis

The unit of analysis was taken to be the proposition, which is a common approach to evaluate concept maps (Zak & Munson, 2008). Each proposition was broken down from the concept map and captured in an excel file. Figure 2.3 shows an excerpt from this spreadsheet to demonstrate what the first step in the analysis looked like.

Figure 2.3[11]

Example of an Individual Student Tab

ade	ES					PA/RA ++	2	core	l <- [left, A <- B]		
nder	Female					PA/RA +	2	ancillary	r -> [right, A -> B]		
nicity	Hispanic or Latino					PA/RA -	-1	asscociated	d <-> [double, A <-> B]		
te	Hispano o Latino					PA/RA --	-2	unassociated	u - [undirected, A - B]		
te	11/17/22 N first attempt to caputre concept/links								no arrow between concepts - leave arrow, code arro		
	11/22/22 BE looks over and provides feedback										
	1/4/23 BE PA/RA scoring										
	1/30/31 discussion with CB - canning is general PA++, change line 12										
	2/6/23 changed PA scoring for FI and war										
	3/10/23 changes in yellow - to fit with plot										
	3/15/23 RA- changed to RA+ because describing a problem with food connection										
											
	First impression horizontal order subconcepts hae drawings, similar to DNE0312, maybe sat on the same table, original shows colors										
	Language conne Teremoto is spanish for earthquake										
	Culture connect ideas for canned food - connection to home										
							Knowledge				
mber of c	From	arrow	Arrow code	To	labeled link	Score	PA	RA	Thought chain	Reasoning/Notes	
1	food innovation	<-	l	food insecurity	none	PA+/RA+	1	1	multiple		
2	food insecurity	<-	l	war	none	PA+/RA+	1	1	multiple	student added drawing of a tank. 2/6/23 changed PA- to PA+	
3	food insecurity	<-	l	ice strom	none	PA+/RA+	1	1	multiple	student added drawing of snowflake, 3/15/23 RA- changed to RA+ because describi	
4	food insecurity	<-	l	fire	none	PA+/RA+	1	1	multiple	student added drawing of fire, 3/15/23 RA- changed to RA+ because describing a pr	
5	food insecurity	<-	l	tornado	none	PA+/RA+	1	1	multiple	student added drawing of tornado, 3/15/23 RA- changed to RA+ because describing	
6	food insecurity	<-	l	teremoto	none	PA+/RA+	1	1	multiple	student added drawing of teremoto, spanish for earthquake, 3/15/23 RA- changed t	
7	food innovation	->	r	ideas	none	PA+/RA+	1	1	multiple		
8	ideas	<-	l	canned food	none	PA++/RA++	2	2	multiple		
9	canned food	<-	l	fish	none	PA++/RA++	2	2	multiple	student added drawing of a fish	
10	canned food	->	r	corn	none	PA++/RA++	2	2	multiple	student added drawing of a corn	
11	canned food	->	r	fruit	none	PA++/RA++	2	2	multiple	student added drawing of a watermelon piece	
12	canned food	<->	d	food innovation	are	PA++/RA++	2	2	multiple	agreed 11/28/22 double arrow between canned food and food innovation	
13	canned food	<-	l	veggies	none	PA++/RA++	2	2	multiple	student added drawing of veggies, changed to PA++ (agreed with Cory 1/30/23)	

Furthermore, a holistic rubric, which is called translation device in LCT language, was generated to score concepts for knowledge, language, and culture in terms of positional autonomy and relational autonomy. The decision to use what is referred to in LCT as a second level translation device, using two levels of pluses and minuses, was made because it is more precise than analyzing only the first level, which simple distinguishes whether the data is targeted or not (with a single plus or single minus). Figure 2.4 shows the translation device developed to score for knowledge.

[11] For further information how maps were set up in excel see Appendix C.

Figure 2.4

Strand Knowledge: Translation Device

PA: Community Food Innovation (CFI)			
PA	*Coding Categories*	*Description of Coded Content*	*Examples from Data*
+	PA++ (core)	Needs to be about CFI, has to have FI AND community connection	Canning (either cooking method or canned food)
↕	PA+ (ancillary)	Needs to be either about FI OR community connection	Connection to nutritious, livestock, hunger.
↕	PA- (associated)	Natural disaster without sense of community. NEITHER community NOR FI, related about food and somehow related to the topic.	Food insecurity – no rain
-	PA - - (unassociated)	Unrelated to the topic or something exotic.	Hanging links, empty bubbles, illegible words, relation does not make sense (e.g., FI – FI).

RA: Improve or solve food insecurity through food innovation (FI)			
RA	*Coding Categories*	*Description of Coded Content*	*Examples from Data*
+	RA++ (core)	FI as a solution to food insecurity	Food insecurity – Ramen
↕	RA+ (ancillary)	If is clearly describing something about food but not proposing a community solution. The word connects with food, even if it is describing a problem.	Connected to food: farm, starvation, livestock, seed, corps, hunger, indoor gardens.
↕	RA- (associated)	Talking about a problem, but concepts/word are not connected to food. No attempt for a solution.	Disasters - Droughts
-	RA - - (unassociated)	Some other reasons why they talk about natural disasters or something exotic.	Hanging links, empty bubbles, illegible words, relation does not make sense (e.g., FI – FI).

Two evaluators then scored the propositions for each strand. This researcher started scoring and the second evaluator reviewed the scores. In case of disagreement, they both discussed the incidents until 100% agreement was reached (American Educational Research Association, American Psychological Association, & National

Council on Measurement in Education, 2014). Additionally, each PA, RA score was connected to a number, such that ++ is represented as +2, which could more easily be plotted on the autonomy plane. Since timestamps were not available to create tours in the autonomy plane, heatmaps were used to display the frequency and the relationships between PA and RA for each strand. These shaded matrixes were created using Python, a statistical program, and then integrated into the autonomy plane, generating a two-in-one image.

Next, student profiles were created by sorting the two-in-one images by appearance within each strand, such as when one quadrant was left-out or if there were scores just in one quadrant. This was helpful to form general rules[12], which described student patterns that became visible, such as 'sovereign knowledge only' when all scores were in the sovereign quadrant for knowledge coding. A generated list of student profiles was helpful to look for trends within each strand and to write up the findings. As this research team did not want to reduce the richness of the concept maps to simple numeric scores (Cardozo-Gaibisso et al., 2019), symbols that represent concepts from the original student maps, such as 'food insecurity' or 'canned food,' were integrated into the two-in one images (see Figure 2.5). The latter idea follows an emerging trend of using art and emotion to add to the portrayal of scientific data (Fleishmann, 2023).

To minimize biases and increase chances that findings are credible (Maxwell, 2013), the broader LaCuKnoS project used prolonged engagement over multiple

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[12] See Appendix H.

years, detailed data collection methods, and contextual fieldnotes to provide in-depth data. Additionally, analytic memos and peer feedback were used for the purpose of this study.

2.6 Results

Findings showed that the Curious Minds positioned themselves as competent knowers and made word choices that suited their communication purposes. But even if there was evidence for especially explicit cultural connections, such as the use of Spanish language, drawings or concepts linked to lived experiences, additional data would be needed to make strong claims about cultural connections.

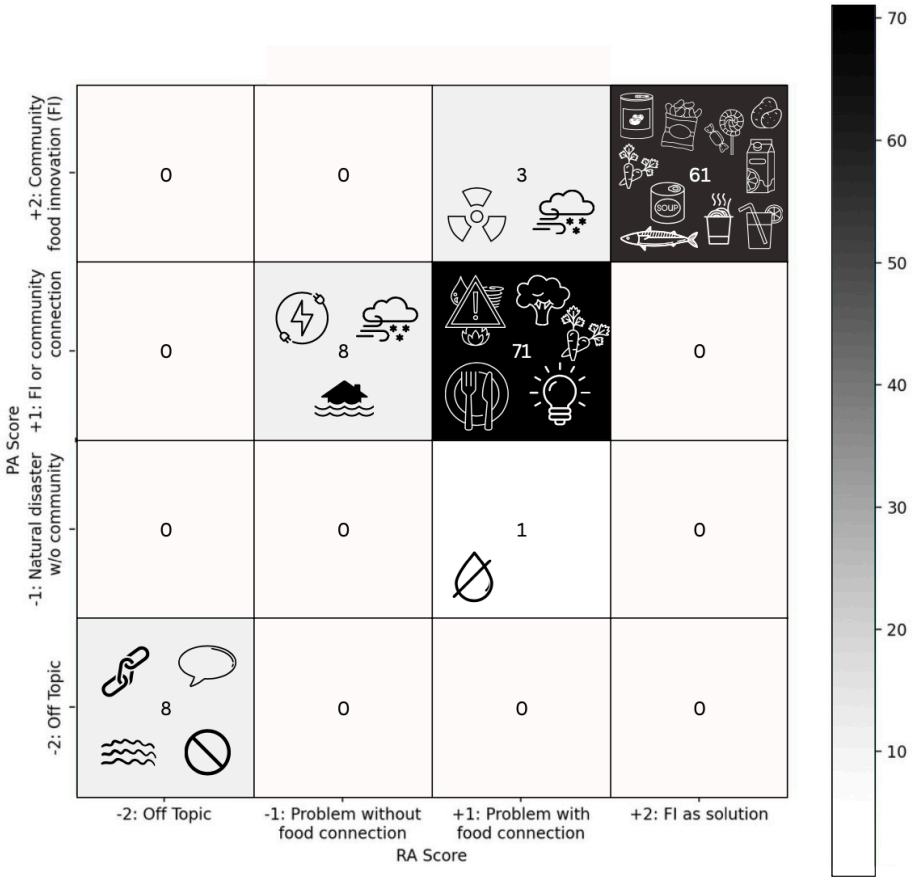
2.6.1 Strand: Knowledge

Students clearly had something to say about the topic of community food innovation (CFI). For example, student profiles displayed a sovereign trend showing that the Curious Minds applied evidence to daily decisions and proposed solutions to solve the community challenge. Five of the 13 concept maps, most from female Latinx students, fit into the sovereign-only knowledge group because they used concepts that were on topic and on purpose. The other eight students displayed a sovereign-dominant knowledge pattern because 50% or more of the concepts were in the sovereign quadrant. Propositions in other quadrants, for example, were either off topic by talking more generally about natural disasters (PA-), had a different purpose by proposing ideas without direct food connections (RA-) or had unclear ideas (PA--, RA--). The findings connect with the LaCuKnoS model and the literature on LCT Autonomy because a person who demonstrates knowledge competence clearly expresses what the topic is about and why it is valuable to learn.

More specifically, figure 2.5 summarizes the concepts used across this club. For instance, students provided examples for natural disasters that cause food insecurity (e.g., earthquake, war), noted different types of canned food (e.g., corn, green beans, peach), described characteristics of and interesting ideas for food innovation (e.g., healthy candy canes; inventions come by surprise, like pink lemonade). 89% of the total concepts were considered sovereign because they were on topic and on purpose. Just 11% of the concepts were in other quadrants. For example, some codes were projected, because even if content related, they had a different purpose such as the one student who mentioned that ‘equipment’ could be ‘gas/electricity’ and thereby described a problem that is unrelated to food and had no attempt for a solution (RA-) but still had a communal connection (PA+). Just one score was considered introjected, such as the student who wrote ‘no rain causes food insecurity’ and thereby talked more general about natural disasters (PA-) but described something about food (RA+). Finally, exotic scores were stand-alone concepts or propositions without a second concept, which this research team refers to as hanging links.

Figure 2.5

Curious Minds Club: Knowledge Scores



Key

ICONS	TITLE	ICONS	TITLE
	Canned Food		Ramen
	Food Innovation		Disaster
	Shelf Stable		Idea
	Nutritious		Food Insecurity
	New Product		Off topic, Off purpose (e.g. hanging link, illegible word)

Note. Autonomy plane with integrated heatmap for the strand knowledge. The heatmap shows the frequency of concepts. Symbols represent the concept that came up the most (from Authors 2023).

2.6.2 Strand: Language

In contrast to the other two strands, the analysis showed no clear language pattern prevalent. Six out of 13 students had a mix-language pattern, which means that scores were found in each of the four quadrants. Within this group students used a number of other words (e.g., ideas, corn, peaches) in addition to the starting words they were given to describe a practical real-life solution such as 'prunes are nutritious' (PA+, RA++). Candy was a tempting idea, such as the one student who mentioned 'candy as food innovation' (PA+, RA++) or the other student who came up with the idea of 'healthy candy canes' as a CFI (PA++, RA++). The remaining seven students showed a variety of patterns, such as sovereign-left out language, which means that there were no scores in the sovereign quadrant. This pattern fits Juan's concept map, for example, a male Latinx student, who mostly used pre-given words (PA-) that fitted multiple purposes, such as using 'can food' as a real-life example for CFI (RA++) or being vague when saying that 'food innovation needs to be nutritious' (RA+). Summarizing, the various language patterns mirror that the students' language choices are as colorful as language itself and that concept maps gave students an opportunity to apply this repertoire in the context of an authentic community challenge.

Even if students got a short list of words to get them started and this researcher's map was displayed in class, 62% of the total concept words used came

from the students (PA+) and only 38% from the researchers (PA-). Although it could be distinguished which concepts came from the researchers because they were words from the template and/or the expert map, it was impossible to determine which ones actually came from the students, from peers if they worked in groups or from the teacher. Yet, it seems that the pre-given words did not dominate the students word choices, rather they were encouraging to come up with other words, such as ice storm, or hurricanes. It seemed that the topic of food plays a central role in everyone's life, which probably made it easier for elementary students to manage the given task. The heterogenous language pattern shows that students made flexible word choices for science sense making to communicate their purposes. This relates to the LaCuKnoS model, which views language as functional, achieving the goal of communicating ideas rather than checking whether language is used appropriately.

On another level, concept maps provided opportunities to use multiple language modalities, such as drawings and the use of translanguaging rather than revealing ideas in written English only. Many students used drawings as visual supports, such as the one student who had a picture of a tank that symbolizes the concept 'war'. Others used stars or emojis to decorate their maps, highlighted important words or replaced words with drawings. Even if there were only four incidences, some translanguaging occurred as well, such as the one student who wrote 'terremoto' instead of earthquake. It seems that most of the multilingual students felt comfortable creating their map in English, which was not a requirement for this activity. This connects to the LaCuKnoS model, which promotes the use of multimodalities and translanguaging.

2.6.3 Strand: Culture

Largely, the concept map activity was an attempt to make science learning 'authentic' by connecting disciplinary content to community needs and assets through social problem solving, all skills that are central to the LaCuKnoS model. Students could strengthen their science interest by solving a problem that possibly could happen in their community. The task was challenging for the students because an emergency, such as supermarkets closing due to a power outage so food could not be sold, did not happen often in their community. Yet, with support from peers and adults, students were able to combine familiarities, such as an ice storm (PA+) that happened in the area they live in with learned experiences, such as war (PA-) to come up with a solution for how to solve the problem. As such the Curious Minds took on agency and made choices about which concepts would be part of their map, and which would not.

More specifically, most students presented a sovereign-dominant culture pattern, which means that 50% or more of the concepts were on topic and on purpose. For example, concepts like canned food, carrots, fish, cockroaches, or corn are connected to the topic of CFI and are feasible solutions to solve the problem of food insecurity. Students in the projected left out culture group, presented the second biggest group within this strand. They mainly used learned concepts (PA-), such as war, which were either unrelated to problem solving (RA-), such as the proposition 'tsunamis cause food insecurities' or used words that were scored as exotic because they made no sense, such as a stand-alone bubble (RA--). One student showed a mixed culture pattern where scores were in each quadrant and another student

displayed a sovereign-only pattern showing most of the scores in the sovereign quadrant.

Overall, there was evidence that hinted at some explicit cultural connections (Lizardo, 2022). For example, some students mentioned concepts which were connected to their home or communities, such as food or natural disasters like wildfire or ice-storm (PA+) that have become increasingly common in this region in recent years. Fully considering which events students have experienced and which events they have been taught about would require follow-up questions that could not be conducted at the time these data were collected. As already mentioned, some students used colored drawings, which raised additional questions, such as their affinity for drawing and/or colors, when and why a written word might be replaced with a drawing or what does this drawing mean to the student. Again a few other students used Spanish words that led to the assumption that they have comfort with a language other than English. The patterns that can be observed could hint at explicit cultural connections, but more in-depth data is needed to show if concept maps are a useful tool for exploring such cultural connections.

2.6.4 The Value of Coding

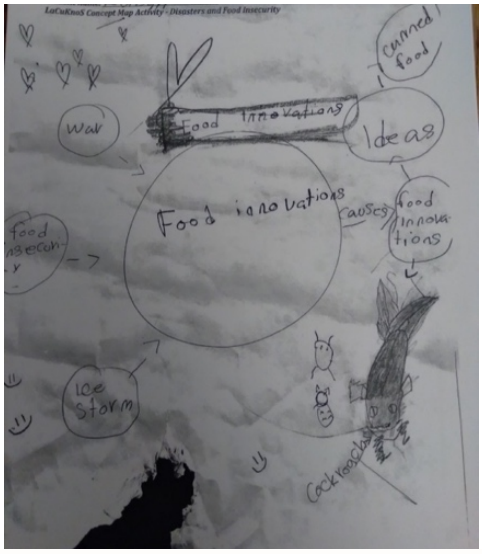
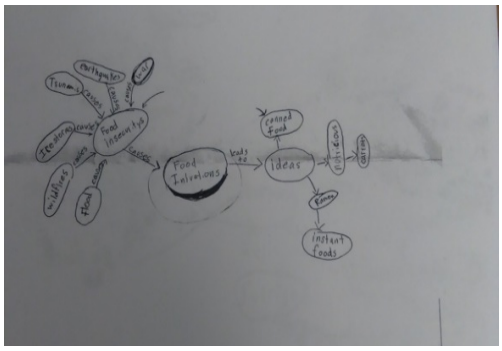
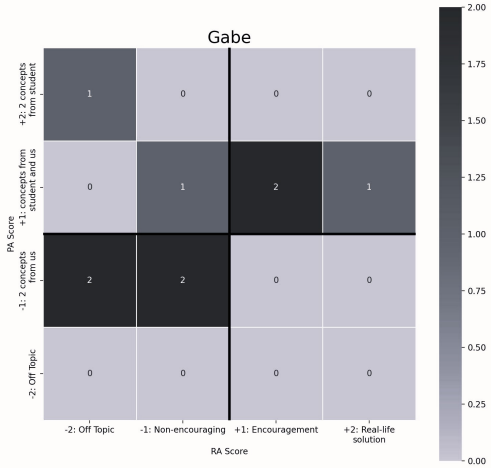
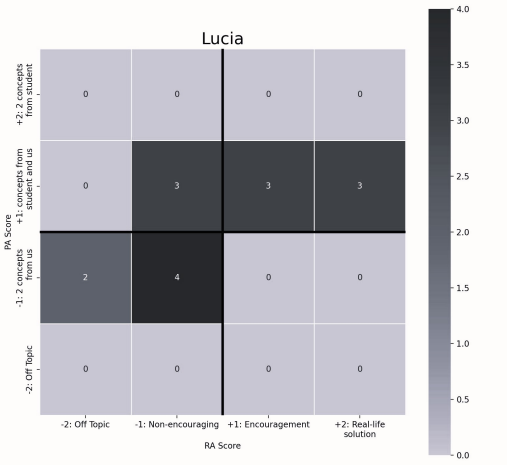
The following mini cases point to the value of coding and at the same time stress the feasibility of using LCT autonomy codes for multiple purposes, rather than using them for studying knowledge practices only. If this research team had not applied LCT Autonomy these differences would not have been noticeable.

2.6.4.1 Mini Case 1: Different Map Structure but Same Language Relationship. Lucia's and Gabe's maps look different at first sight but have a similar

language relationship (see Table 2.1). Gabe filled the whole paper with single thought concepts, using drawings instead of words and drew smileys as decoration. This map seems more unstructured compared to Lucia's, which has a horizontal shape, most links are labelled, using multiple thoughts to capture ideas. Yet, the two-in-one visuals reveal that both maps are in the introjected left out language range. In other words, the introjected quadrant (PA-, RA+) had no scores because students did not apply pre-given words to encourage that something needs to be done. Instead, they used the pre-given words (PA-) to describe a problem, such as war causes food insecurity (RA-). Yet, they also came up with other examples, such as instant food (PA+), which is a real-life solution (RA++). Thus, while the maps look quite different at first appearance, analysis indicates that the maps are doing much the same linguistic and conceptual work.

Table 2.1

Gabe and Lucia's Concept Map

Student	Gabe	Lucia
Concept map		
Two-in-one visuals: Introjected-left out language pattern.		

2.6.4.2 Mini Case 2: Same Map Structure but Different Language

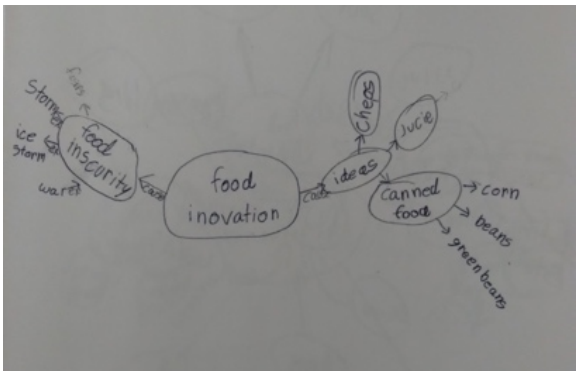
Relationship. This mini case shows the opposite effect compared to the previous one. Elena's, Lucia's, and Martha's maps almost look the same but show a different language pattern (see Table 2.2). All maps have a vertical structure, using arrows that connect multiple thoughts, most of the links are labelled and all sub concepts are

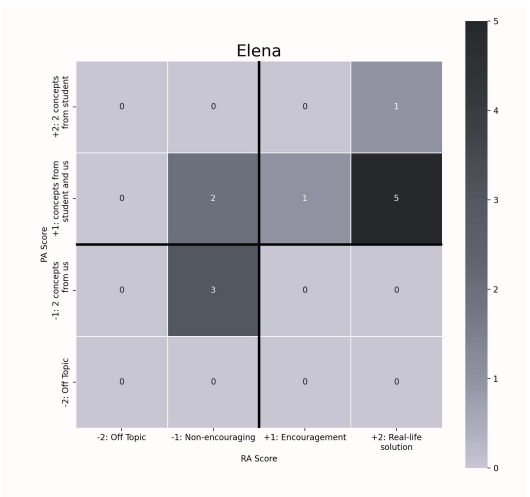
structured around three main concepts. Yet, Elena's concepts fall into the sovereign-dominant language pattern because 50% or more of the concepts fits the topic (PA+) and the purpose (RA+) even though there are no scores in the introjected quadrant. Lucia's map instead displays an introjected left-out language pattern because there are no scores in the introjected quadrant, indicating that she did not use pre-given words (PA-) to propose a real-life solution (RA+). Finally, Martha displayed a mixed language pattern. She has scores in all four quadrants, because she used a mix of non-pre-given and pre-given words to propose (RA++), encourage (RA+) or just describe (RA-) a solution that could solve the problem.

Table 2.2

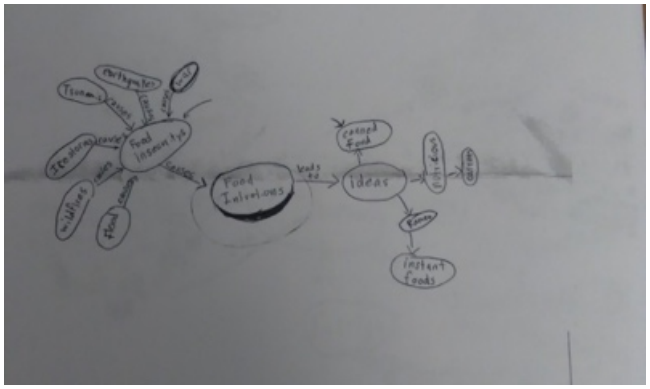
Elena, Lucia, and Martha's Concept Map

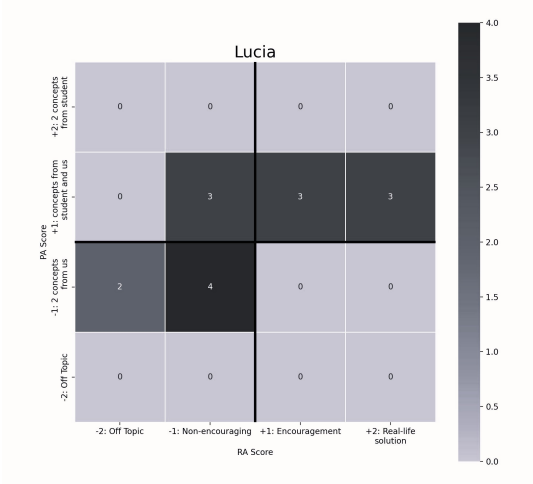
Elena: Sovereign dominant language



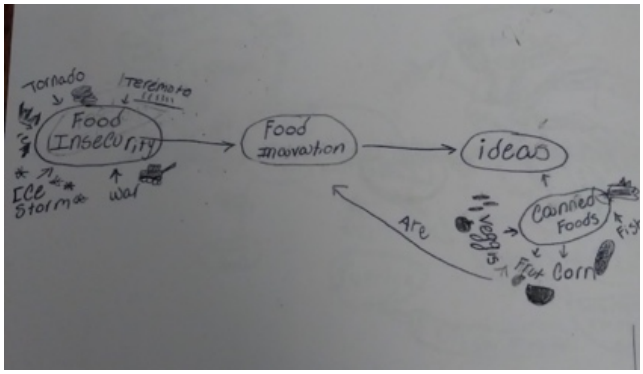


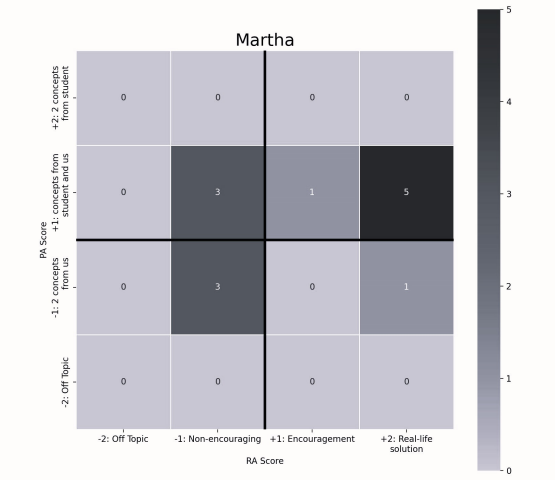
Lucia: Introjected left out language





Martha: Mixed language





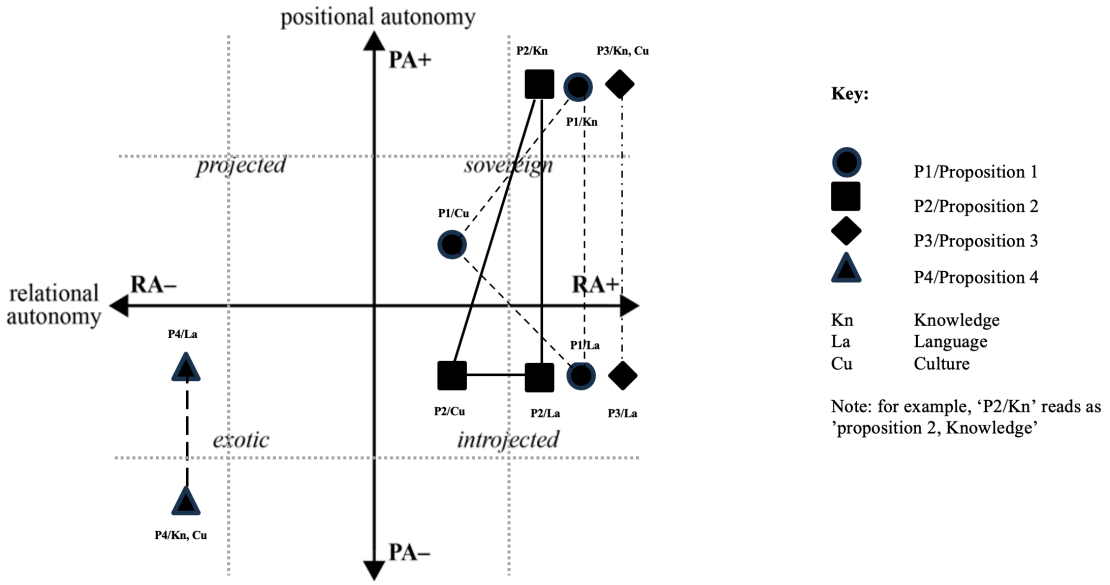
2.6.4.3 Mini Case 3: A Three-Strand Tour. Angel's concept map (see Figure 2.1) was one of the smaller ones and was chosen to display how propositions tour in the autonomy plane across the three strands. Figure 2.6 demonstrates that in contrast to effective instruction which ideally starts and ends on target, learners' thoughts journey into and through multiple quadrants depending on what is helpful for the learner to both understand and make personal connections. For example, proposition four (P4) consists of only one verb (causes), which was considered a stand-alone word. P4 moves from associated exotic to unassociated exotic, because the word was pre-given (La/PA-) but being isolated on the concept map did not make sense from a knowledge and cultural perspective. For knowledge, the other three propositions (P1, P2, P3) are in the core sovereign quadrant, because they were on topic and on purpose. Regarding language, they all travelled into the introjected quadrant, because the student used pre-given words (PA-), such as food innovation, to describe a practical real-life solution (RA++), such as Ramen [noodles]. Even if in Angel's case there is a clear sovereign knowledge and introjected language trend visible, the cultural codes do not follow any pattern. In fact, they are heterogenous because the learner made either personal connections or used learned concepts. For example, concepts like 'Ramen [noodles]' or 'can food' might be personally familiar to the student, but war (PA-) assumingly might not. Yet, even if concepts were feasible solutions, just 'can food' was considered culturally connected (RA++).

Summarizing, the three-strand tour could be an effective tool to help educators understand how to strengthen the relationships between academic content to be

learned and students' reasons for learning it by simultaneously attending to the language, culture, and knowledge aspects of student work.

Figure 2.6

Three-Strand Tour



Note. Thoughts traveling within the autonomy plane using multiple perspectives. Symbols are placed in the sub quadrants according to their PA, RA combinations but the actual position within those is arbitrary (from Author, 2023).

2.7 Discussion and Conclusion

This study set out to answer the following research question: How do elementary students' concept maps from a multilingual after school science club reflect their sense making during a science lesson in ways that support students' (a) science knowledge building for informed decision making; (b) language development for science communication; and (c) cultural and community connections to science.

Findings show that students in this club displayed a sovereign knowledge trend indicating that students positioned themselves as competent knowers when proposing solutions to solve a community challenge around food innovation. The heterogenous language pattern, the use of different modalities and translanguaging implied that word choices were made purposefully to suite the students' communication goals. As such, the use of language was more functional rather than structural. Finally, students brought in experienced concepts, such as food or examples of natural disasters. However, even if there was evidence that pointed to explicit cultural connections, such as the use of translanguaging or art, further information is needed from the students to make meaningful claims about cultural connections.

Mini cases revealed additional patterns that speak to potential uses for this research approach. For example, LCT autonomy codes helped to show that concept maps that look quite different might be doing similar conceptual work, and that on the contrary, concept maps that look similar may show quite different patterns of language use or knowledge application. Moreover, the three-strand tour unveiled that thoughts need to journey into and through multiple quadrants to help the learner understand and make connections.

2.7.1 Implications

Findings showed that concept maps are 'visual roadmaps' (Marzetta et al., 2018, p. 2) that encourage students to make it their own, as there are not too many restrictions on how to construct them. Concept maps allow various modalities and the use of translanguaging, all features that are especially useful in today's diverse classrooms (Buxton & Lee, 2023). This is valuable information for educators because

concept maps can help them recognize not only where the learner is, but also which assets might be built upon. For example, we as researchers learned from the Curious Minds Club that even if maps showed similar propositions or used pre-given words, they all are unique, just like the person who created them. As such students took on agency and decided which concepts would be part of their map and which ones would not. Thus, when asked to construct a concept map there is no need for fidelity of implementation as is often observed in other areas of education (Buxton et al., 2015). Rather students took ownership ensuring that what they learned was responsive to their needs and what they wanted to share about themselves.

However, even if concept maps pointed to some explicit cultural connections, which were obvious, such as drawings or food, at the same time they raised additional questions which could not be sufficiently answered yet. For example, students provided examples for canned food, such as corn or peaches, which could be part of the home culture (Salazar, 2007) but at the same time the concept alone provided not enough information to make these assertions. Nevertheless, these in-between spaces are not new for researchers. Spradley (2016), for example, addressed these issues by acknowledging that research is following cycles because not everything will work out according to plan and follow-up questions will often emerge after the analysis process. Thus, it is up to future research to come up with more detailed questions that are based on the broader ones. Although some patterns were apparent in the data that could hint to explicit cultural connections such as art or food, the evidence was not yet sufficient to make useful claims.

Like concept maps, LCT autonomy codes have typically been used to uncover shifts in knowledge practices, but this study found that these codes were also a useful tool to analyze concept maps from different perspectives. In contrast to conventional holistic approaches to analyzing concept maps (Ries et al., 2021) which use a rubric that creates poor, better, or best hierarchies, the LCT translation device focused on two aspects (topic and purpose) and how they relate to each other (Maton & Howard, 2018, 2020). Thus, LCT autonomy analysis was found useful to provide information in a non-judgmental way about the nature of concept maps that would not have been apparent just by looking at them. The notion that content and purpose of a learning interaction are connected was a central premise as we scored concept maps in a new way. Yet, when displaying the findings on the coordinate plane we struggled to avoid reductionism of the students' ideas as the richness of the concept maps got reduced to points in the various quadrants. In response to this shortcoming, heatmaps were used, as well as art to portray scientific data (Fleishmann, 2023). However, this holistic rubric might not be ideal for all areas of interest, such as culture, which require additional in-depth information. Therefore, when searching for alternative ways of analyzing concept maps, it could be helpful to combine LCT with other analysis tools, such as discourse analysis to provide more in-depth information (Bartlett & O'Grady, 2017).

2.7.2 Limitations

There are limitations, which others may wish to consider: (a) This study focused on students' artifacts only, which left room for misinterpretations of students' intentions for their concept maps, especially when it comes to implicit cultural

connections or to distinguish which word choices came from the students or the teacher. Additional studies of students' perspectives using interviews, think alouds or recordings of the lessons would add to this body of research. (b) There was the missing temporal dimension in how data was collected. As we had no detailed information about how students drew their maps, such as which word came first and which one was next, we were not able to show autonomy tours in the traditional way that has been used by other LCT researchers. Time also played a role whilst scoring because this kind of work turned out to be unexpectedly labor intense. (c) Finally, this proof-of-concept study used the concept maps from one club only. Moving forward with the LaCuKnoS project, LCT autonomy codes will be applied to a larger data set, which includes hundreds of concept maps to see what patterns occur in cross-case as well as within case analysis.

2.7.3 Conclusions

The outcome of this study provides ideas for educators and researchers. We offer it as a new framework for science teachers in supporting all students, and especially multilingual students, with the conceptual and linguistic practices as well as skills they will need to succeed in school and in the workplace. Concept maps can help educators and researchers to find out where students are, what they bring to the table and in which areas support is needed. Students sometimes provide this information unintentionally, but if teachers make things more explicit, students would do it more purposefully.

Yet, this approach to scoring concept maps using LCT Autonomy is time intensive, which would likely deter educators from using it. In other words, without

time and support to make this new approach fit for individual teaching purposes, educators may continue using traditional strategies, which are becoming less and less suitable in today's diverse classrooms. Thus, the promising results from this study could prompt researchers to seek ways to automatize the scoring using new technology, such as the use of artificial intelligence (Jia et al., 2024). Programs like SBERT, for example, could be useful to code data sets such as concept maps. In any cases this study should encourage researchers to think outside the box and apply contemporary perspectives to traditional approaches still used in many science classrooms.

3. ‘What is the point of doing this?’: How Teachers and Researchers Create Figured Worlds of Concept Mapping

3.1 Abstract

The contemporary term identity artifact is used to describe something a person has produced that is of educational use. Concept maps, it is argued, are examples of identity artifacts because they highlight today’s understanding of culture as one of many elements that make up a person’s identity. As such, concept maps can unveil what is meaningful for the students in an educational context. This qualitative study used figured worlds theory to bring together the expertise from ten after-school science teachers and two researchers about concept mapping. Findings described how maps created multiple systems of meaning and at the same time were perceived differently between and within these as-if worlds. Narratives brought up insider information that could be useful for both teachers and researchers to gain further insights about the student and on which assets to build. Moreover, a shift in perspectives could, for example, lead the teacher to position the student’s work differently, which is valuable for all but especially for students who already experience educational disadvantages. Teachers who conduct at least a minimal analysis of concept maps will discover that it can be worthwhile because the findings contain helpful information about what is important to students or how they understand things, which in turn can be a motivator for learning if incorporated into future teaching.

Keywords: Concept Maps; Identity Artifacts; Figured Worlds Theory

3.2 Introduction

Students are continuously given opportunities to demonstrate what they have learned in science classrooms, such as by writing a lab report, drawing themselves as scientists or constructing concept maps. These tasks are helpful for students as they get a chance to practice additional skills, such as reading or writing, while also providing them with the opportunity to show others what is meaningful in their lives. Concept maps, for example, in their function as graphic organizers not only show what a student knows about a topic (Reiska, et al., 2018), they also provide information about the students' language choices and show connections to personal experiences (Ettenauer et al., 2023a). Thus, concept maps are artifacts, which hold insights about the students' interests, skills, and even their identity, which is valuable information for educators to adjust their teaching and support learning.

The busy school life makes it challenging to find enough time and resources for teachers to give those little details the attention required. Furthermore, chances are high that these identity artifacts (Subero et al., 2018) are reviewed too quickly causing teachers to position students without noticing these hidden treasures. However, research has shown that what is said or done no matter how subtle affects the teacher's relationship with the students (Cummins, 2001) and subsequently impacts students' identity because it is co-constructed through the interaction with others (Reeves, 2009). Harklau (2000), for example, described that the images teachers created about their students, such as the 'good kids to the worst' (p. 35) impacted their identity, which could lead to either limited educational chances or to increased educational opportunities. Thus, considering identity artifacts as teaching

tools and knowing how to evaluate them could be an additional support for teachers as they consider their students' science identities.

This study uses the term identity artifacts instead of cultural artifacts because in today's multicultural society culture is more fluid than it was in the past, and people use culture in new ways (Davidson, 1996). In fact, identity is influenced by many factors and not just culture. Thus, this paper follows the more recent definition from Subero et al., (2018), who defined identity artifacts as something that was produced by a person and has educational use. Researchers showed that identity artifacts are helpful tools to unveil what has significance for a student and how this in turn connects to the curriculum, such as a shoebox filled with objects, which are meaningful for the student (Subero et al., 2018). Applying this understanding to concept maps means that these maps can be used to provide insights about a student that go beyond conceptual understanding, but at the same time require at least a minimum of analysis to make connections clearer before they can be used in an educational context.

The broader goal of this paper was to bring together educators and researchers' expertise about concept maps to describe how they function as identity artifacts to gain valuable information about the students' skills and strengths as well as providing insights about how to optimize teaching and evaluation. Data came from a project called LaCuKnoS (Buxton et al., 2022), short for language, culture, and knowledge-building through science that builds on the premise that knowledge, language, and culture are intertwined. Ten teachers from eight after school science clubs from the Pacific Northwest and two researchers who participated and worked

on the larger project provided the data for this study. As such, this paper analyzes U.S. teachers' and researchers' narratives about concept maps by using Holland et al.'s (1998) figured worlds theory to answer the following research question: How does thinking about concept maps help teachers figure about supporting their student's science sense-making?

3.3 Literature Review

3.3.1 Why Identity Artifacts?

It was Vygotsky, who focused on cultural tools, also known as cultural artifacts, and how these shape people's thinking and actions (Cole & Wertsch, 1996). Artifacts are everything people create and use, such as objects, language, signs, or symbols. They are considered cultural because they influence people's shared values, beliefs and norms and are perceived differently in societies. As such, they also play an important role in research in fields such as education or anthropology. Holland et al. (1998), for example, studied how cultural artifacts, like add-a-beads are used in realms called figured worlds to characterize people acting in these worlds and how they shifted their understanding through their actions and imaginings. Although beadwork, which is a way to individualize jewelry, has different meanings in various cultures (e.g., religion, form of money), in the figured world of romance at a high school they were a symbol of beauty. At this time, culture was considered more homogenous because people's ideas were thought to follow broad norms. Moreover, culture was seen as the primary influence that caused people coming from various ethnic societies to form their identity (Davidson, 1996).

Yet, in the fast-moving 21st century with culture becoming more fluid this traditional understanding of culture and its influence on individuals is no longer adequate. Rising immigration rates in the U.S., for example, led to changes in the American society resulting in new ideas about multiculturalism and diverse classrooms (National Center for Education Statistics, n.d.). The effects of immigration on the traditional cultural understanding were already the subject of debates amongst scholars in the 1990s. Researchers like Davidson (1996) argued that the influence of culture in people's live have to be reconsidered because 'social categories are more complex and multifaceted' (p. 31) and that there is evidence that people started to employ culture in new ways. Rodriguez (1982), for instance, described how he had to leave his working-class Latino self behind when faced to succeed in the U.S. school system. Thus, culture from a contemporary perspective is dynamic and changes rapidly. Today people start to construct their identities based on a variety of factors, and culture is just one part of it.

One could ask now whether the term 'cultural artifacts' does justice to today's contemporary understanding. Considering that artifacts are created and used by people living together in a society, they embody certain characteristics of the people who created and used them, whose identities are influenced by many factors and not just culture. Thus, researchers like Leander (2002) started to take on this new perspective by introducing the term identity artifacts, which was broadly defined as 'any instrument (sign, material object, embodied practice, etc.) that interactants make use of to shape the identity of an individual or group' (p. 199). Findings from this study (Leander, 2002) showed that identity artifacts such as student's talk or group

work functioned in oppressive ways to help create and maintain a student's identity described as 'being ghetto' (p. 198). However, even as the author highlighted the harmful consequences of identity artifacts, he encouraged the field to also think about positive ways to use these, such as when giving feedback on students' work.

Recently, Subero et al. (2018) modified Leander's term to demonstrate, even if not empirically proven yet, that identity artifacts are equally useful for improving teaching and learning and not just for studying interpersonal relations in the classroom. Authors define identity artifacts as 'productions based on the experience people have of themselves – including whatever is meaningful for that person (people, objects, activities, spaces, institutions, etc.) – which also require, in order to be made, the application of curricular content or competencies.' (p. 163) According to this definition identity artifacts inherit two criteria: (a) it is something a person produced and (b) it needs to be of educational use. In their more theoretical justification Subero et al. (2018) referred to a paper written by Mantei and Kervin (2014) who studied middle schoolers' artwork, which was created based on a picture book. Findings showed that students built on their funds of knowledge and connected parts of the story with personal experiences. Thus, the artwork signaled the student's voice and supported literacy engagement. As this article focuses on how teachers can support students' science learning through the use of concept maps, Subero et al.'s (2018) definition of identity artifacts seems the most appropriate.

3.3.2 Concept Maps as Identity Artifacts

Novak and his team (1998) first introduced concept maps in the 1970s by drawing on Ausubel's ideas around mindful learning. As such, they are visual

representations that show how ideas are related to each other (Oliver, 2009). Concept maps have certain defining characteristics, such as concepts being linked by arrows or lines, which are then labeled with a word or phrase that best describes the relationship between the linked concepts. A proposition is the typical unit of analysis for concept maps, composed of two concepts and the labeled link, which then reads like a short sentence (Zak & Munson, 2008). They can be drawn by using paper and pencil, constructed with physical objects such as toys, or using computer software like Cmap or Inspiration. Although it seems that concept maps are used less often in today's science classroom, they remain useful tools for teaching (Oliver, 2009), assessment (Reiska et al., 2018) and research (Ries et al., 2021).

Concept maps have been found effective because they mirror a person's cognitive structure and show what a person knows about a topic (Reiska et al., 2018). However, recently other researchers (Ettenauer et al., 2023a) found that concept maps unveil more specifics about the person who constructed them that goes beyond conceptual understanding. Thus, concept maps also provide information about the person's language choices and show examples that connect back to things that were experienced by the learner. Considering the different ways students apply, for example, knowledge or language connections in their concept maps, they resemble the students' voice and provide details about their identity. Additionally, concept maps are of educational use, because they provide information for teachers, for example, about student assets that can be built upon in subsequent instruction. Thus, concept maps can be considered as identity artifacts because they fulfill Subero et al.'s (2018) criteria.

3.4 Theory

This study applied a contemporary perspective on artifacts and therefore used the term identity artifact instead of cultural artifacts to analyze the multifunctionality of concept maps through the lens of figured worlds theory (Holland et al., 1998). The following provides an overview about the role of artifacts in the context of multiple figured worlds.

3.4.1 Figured Worlds Theory

Holland, Lachicotte, Skinner and Cain's (1998) figured worlds theory builds on work from several scholars, such as Bakhtin or Bourdieu but was primarily influenced by Vygotsky's (1978) observation of children at play. In contrast to the child's imagined play, where a stick becomes a horse, adults create collectively accepted systems of meaning through their day-to-day activities, such as the figured world of a science classroom where a teacher and students come together to learn about science (Ryu, 2015). Thus, a figured world is a 'socially and culturally constructed realm of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others' (Holland et al., 1998, p. 52).

These as-if worlds develop over time as individuals act and interact with others in certain contexts, which produces a shared knowledge and narratives for individuals in these systems (LaDousa & Baldrige, 2017), for example, the shared assumption that refugee students are different than their peers (Bal, 2014). Harklau (2000) used the term 'representation' (p. 37) to describe the images or even stereotypes people create whilst they make sense of themselves and others. Yet, these

interpretations are dynamic as people interact with each other in ways that may result in a change of their thinking. Thus, identity in figured worlds is created through participation as individuals are forced to find their role and get a sense of belonging (Robinson, 2007).

As much as figured worlds offer people opportunities for social action, hierarchies or social status simultaneously constrain their possibilities to act and how they are seen by others (LaDousa & Baldrige, 2017). Examples for this are the 'good reader' (López et al., 2015, p. 192) or the way students work is interpreted at school (Ryu, 2015). Agents in figured worlds construct positional or relational identities for themselves and others that indicate power dynamics or privileges (Ryu, 2015), which are adopted especially by participants who have less power in these systems, such as students in schools (LaDousa & Baldrige, 2017). Thus, it is important to show students and their work in a way that highlights the strengths and connections they are making. Figured worlds theory, for example, offers such opportunities.

Nevertheless, artifacts, such as verbiage or objects have a special significance in figured worlds because of their multifunctionality. Such artifacts may have different meanings depending on who uses them in what context, for example the report card that informs about a student's progress in school is perceived differently by caregivers than by the student. Additionally, artifacts can create a figured world of their own, such as the artifact 'success', which could describe, for example, what it means to be successful in a bilingual high school (Michael et al., 2007). Moreover, they cross multiple figured worlds (Holland et al., 1998), for instance, being 'smart' at school and outside of school is somewhat different (Hatt, 2007). Finally, artifacts

have the power to shift people's perceptions and by doing so, to create new figured worlds (Ettenauer et al., 2023b), assist individuals to author new stories (López et al., 2015) or help people to find their role and belonging in these systems (Robinson, 2007). This paper frames concept maps as identity artifacts to highlight today's fluid understanding of culture.

Summarizing, several elements, including identity, positionality, dynamic, and artifacts, influence and depend on each other in figured worlds theory, which makes this framework a bit vague. Yet, it is a powerful approach that inherits the idea that these as-if worlds can change at any time and in turn create worlds full of possibilities. This study takes up this idea by describing how two figured worlds can benefit from each other and potentially cause their agents to consider concept maps and therefore the students who constructed them in a different light.

3.4.2 Artifacts in Figured Worlds Research

Even if figured worlds theory is considered a useful approach to study socio-cultural phenomena in education, researchers have sometimes used only parts or combined certain elements of this theory to fit their needs (Urrieta, 2007). Amongst scholars who have used elements of figure worlds theory, identity is the most studied area. For example, Varghese and Snyder (2018) focused on preservice teachers' professional identity in the figured world of dual language teaching and found that relational identities with the students were causal for teachers to take on agency. However, there are fewer studies that deal with artifacts and their impact on these systems.

The emerging literature on the role of artifacts within figured worlds theory pursues two purposes. First, some studies describe how artifacts, which are basically everything created and used by humans, are helpful for people acting in these systems. For example, Robinson (2007) found that verbal artifacts like the saying 'stinky pilgrim' (p. 205) encouraged students to find their role in the figured world of history learning. Others (López et al., 2015) studied how a tangible artifact like a book opened up options for students to value writing about their personal and community related experiences in the figured world of a bilingual elementary classroom. Still others (LaDousa & Baldrige, 2017) showed that artifacts like knowledge or a caring teacher were helpful for students to pass the General Education Development (GED) test in the figured world of a literacy center. Thus, artifacts like verbiage, objects or even skills enabled agents to accomplish something, such as passing a test.

Second, even if the focus of figured worlds was not always primarily on artifacts, some scholars dealt with the idea of how they create and/or cross multiple figured worlds. Hatt (2007), for example, found that the artifact of smartness had a specific relevance for urban youth in different contexts, such that being smart on the street was quite different than being smart at school. Others (Ettenauer et al., 2023b) analyzed how artifacts like relationships changed teachers' perspectives in the figured world of multilingual family engagement resulting in a new world where families were seen more as equal partners. Still others (Swanson, 2019) studied how middle school students acted in multiple worlds – real and imagined figured worlds - during a science lesson that used drama to learn about the historical sinking of a ferry, which

allowed them to learn science but also take on a fictious science identity. Finally, Mehta (2023) found that multiple figured worlds develop, and deal with each other during the process of identity formation. Thus, artifacts like attitudes or even relationships can create and cross figured worlds, whereas multiple systems have the potential to interact with each other.

While much is known about how artifacts influence agents in figured worlds and how people perform in multiple systems, little is known about how multiple figured worlds come together, resulting in the possibility of changing the agent's perception about the person who created the identity artifact. This study aims to close that gap.

3.5 Methods

This study used data from a project called LaCuKnoS (Buxton et al., 2022). The qualitative approach was found more applicable as it gave participants a voice to share their understanding about and experiences with concept maps (Creswell & Poth, 2018). Holland et al.'s (1998) figured worlds theory was used to describe how concept maps created two mutually independent figured worlds resulting in various opinions about the students' work between, but also within these systems.

3.5.1 Setting

LaCuKnoS collaborates with a university pre-college program, which aims to support underrepresented students in STEM while also providing professional development resources for teachers. Schools who participate in this program offer after-school science clubs across multiple grade levels, starting with 4th grade, and are led by a math or science teacher from the local school. A highlight is the annual

challenge event, where students from all clubs come together to work on a complex STEM based problem. In April 2022 the challenge took place at the local schools, rather than at the university, due to COVID-19. The concept map activity served as an introduction to the topic of community food innovations in response to natural disasters. 20 out of 29 active clubs participated and submitted a total of 195 concept maps.

Clubs for this sub study were selected based on convenience sampling (Marshall & Rossman, 2016) choosing only those whose teachers were willing to conduct a follow up interview to share their experiences with concept maps as part of the challenge. Thus, this paper focused on ten teachers working in eight clubs, that were geographically located in urban and rural areas in the Pacific Northwest and that turned in a total of 73 concept maps. Four of these eight clubs were at the middle school level and two each were elementary and high school clubs. In terms of demographics most of the students had a predominantly Hispanic background, while two clubs had a predominantly white student population (Oregon Department of Education [ODE], 2023).

3.5.2 Participants

The ten teacher participants were composed of five females and five males, four of them identified as White, two as Hispanic or Latino, one as Asian, and the rest as 'other.' Educators teaching experience varied from over 20 years of teaching to novices who were in their first year of teaching. Just four teachers had an English for Speakers of Other Languages (ESOL) endorsement to support students' language development, but most of them taught students identified as English Learners (ELs).

In the broader study, informed consent was obtained from the teacher participants and parents/guardians were sent an opt-out consent form to complete at the start of the school year.

Additionally, a senior male and junior female researcher who were responsible for analyzing concept maps from a socio-cultural perspective in the larger LaCuKnoS project also contributed to this study. As far as researchers' demographics both identified as White, whereas one researcher had a European and the other had an American background. Even if both were familiar with the idea of concept mapping, they were new to the analysis of concept maps as practiced in this project.

3.5.3 Data Collection

Teacher interviews were conducted between June and October 2022 via Zoom. The interviews were semi-structured[13] and took about 30 minutes. Open-ended questions addressed topics like personal experience with and understanding about concept maps and sharing goals when teaching the introductory lesson about community food innovations caused by natural disasters. During the interview, teachers had the opportunity to look at the concept maps their club created to have a more in-depth conversation. All interviews were recorded, transcribed with the TEMI automatic transcription app, and then reviewed to assure that transcribing was accurate, and identifiers were removed.

Data that speaks to the researchers' figured world was collected between April 2022 and February 2024. The primary data source included concept maps created by

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[13] See Appendix J: Interview Guide

73 students from the eight participating clubs. Individual and entire club heatmaps constructed from the coded maps, as well as student profiles for the areas of knowledge, language, and culture served as examples for the holistic scoring. Additionally, memos, interviews, and recordings of the discussions between researchers were collected to capture the role of concept maps in the larger research project. Recordings were transcribed with the TEMI transcription app and reviewed for accuracy.

3.5.4 Data Analysis

In order to describe the characteristics of multiple figured worlds, a codebook (see Table 3.1) was developed to deductively code the data (Creswell & Poth, 2018). At first data was coded for figured worlds characteristics, such as experience, understanding or positioning. In a second step, data in these categories was compared and contrasted at the club level using a Venn diagram[14]. The usage of visuals, which follows an emerging trend to utilize art to portray scientific data (Fleishman, 2023), was helpful in developing inductive codes (Creswell & Poth, 2018), such as how participants perceived identity artifacts, shared insider information, or helped to uncover blind spots.

[14] See Appendix K.

Table 3.1

Codebook

Code	Description	Examples from data
1. Thinking/understanding about concept maps	Describes how participants perceive or understand concept maps.	"There's no right or wrong, it's just how are you relating to yourself to the map." (T10)
2. Experience with concept maps (self and students)	Describes how familiar people are people with concept maps.	"… how comfortable I was with CM." (T8)
3. Teacher's support for students during concept maps activity	Support teachers offered during concept maps activity to enable students to construct a concept maps.	"Uh, we did introduce concept maps to our club. Um, but that was just with the challenge." (Teacher 5)
4. Positioning self and others	Positioning happens due to people's social status or place in a hierarchy, history, understanding, experience.	"[team 2] was a little bit checked out with that." (Teacher 3)
5. Identity	People acting in these systems, might become passionate about, have to find their role, and develop a corresponding identity and sense of belonging.	"We said, wow, that's very effective. So, we've been discussing how we might incorporate it into some of the lessons next year." (Teacher 7)
6. Identity artifacts (concept maps)	Identity artifacts (e.g., material, verbal, gestures) are central as they can create and cross figured worlds. Comments about concept maps could fall into 4 categories: 1) General comments 2) Conceptual understanding 3) Language choices 4) Personal, community, cultural connections	<u>1) General comment:</u> "I would expect [it] to be the most detailed ... really likes the rainfall kind of concept map." (Teacher 9) <u>2) Conceptual understanding</u> "Heterogenous trend, students that were close to the topic and purpose (sovereign)." (Researcher 1, club 1) <u>3) Language choices</u> "I think it allowed kids to be able to say, okay, well that's an important word. I should figure out what that means" (Teacher 4) <u>4) Personal, community, cultural connections</u> "We need to stress a little bit more the idea that we, we can make a cultural connection." (Teacher 2)

Note. Codes were created based on Holland et al.'s (1998) figured worlds theory and the theoretical description of its elements using Ettenauer et al.'s (2023b).

In order to ensure that findings are trustworthy (Maxwell, 2013) several techniques were applied. The LaCuKnoS project used prolonged engagement over years, detailed data collection methods, and observation protocols to provide in-depth data. Additionally, peer feedback and analytic memos were used. Yet, knowing that authors hold two positions – being a storyteller and a researcher – and not having a teacher as a co-author on board is a limitation of this study. Regular talks with all teachers who participated in the LaCuKnoS project, such as during workshops, fostered a multi-year relationship with the teachers that is built on trust and open communication that in turn helped to overcome this limitation.

3.6 Results

Students from eight after school science clubs constructed concept maps, which in their role as identity artifacts created and crossed two as-if worlds – the teachers' and the researchers' figured world. Even if these two systems shared general characteristics of Holland et al.'s (1998) theory, such as people's understanding about concept maps or the way they identified and positioned themselves and others, they also point to clear differences between these two figured worlds of concept mapping. Moreover, maps were perceived differently not just between, but also within the figured worlds. Even if views may differ, artifacts can change people's perspectives, which could lead to students being positioned differently in these systems.

3.6.1 How Concept Maps Create Figured Worlds

Teachers and researchers' narratives about students' work portrayed two figured worlds of concept mapping – the teachers' (TFG) and the researchers' figured

world (RFG). People coming into these systems had different experiences, understandings, and histories with maps, causing agents to position themselves and students in a way that makes sense for them. Findings showed two major differences between these two as-if worlds: (a) Teachers expressed a more conventional perspective when thinking about concept maps whereas researchers shared a contemporary understanding. (b) Researchers saw a lot of potential for the use of concept maps in science education, whereas teachers did not use them often in their teaching.

3.6.1.1 Teachers' Figured World (TFG). Almost all teachers expressed a conventional understanding of concept maps, viewing them as a tool that reveals what a person knows about a topic (Reiska et al., 2018) but teachers had different opinions for whom concept maps might be beneficial. Most of the teachers expressed that concept maps were helpful for teachers to 'see if they [students] really understood it' and 'which gaps to fill' because it 'shows connections' and 'helps organize' ideas about a topic. Two teachers found concept maps to be useful for students as 'it is a cool way to see exactly how much they got out of it' because 'there is no right or wrong' and students write more ideas on paper compared to short answer questions. In contrast, one teacher mentioned that concept maps embody different worldviews and therefore demonstrated a more contemporary understanding. This teacher said when sharing more details about the discussion this club had before they actually constructed the maps:

> "And so, their view of the world is very, um, volunteer filling community needs and all that kind of stuff. And so, they were coming up with a great list

> [of ideas] versus other kids who didn't have as much service mindedness" (Teacher 9, interview 10/4/22)

When explicitly asked, other teachers acknowledged that concept maps can also show language, personal, community or cultural connections. As for language connections, for example, almost all teachers said that concept maps help with vocabulary usage, word choices, and encouraging students to think about the relationship between concepts. In contrast to the connections teachers made between language and concept maps, the term 'culture' was viewed differently. Most teachers clearly saw direct connections between food and culture, because 'food is a cultural choice.' Whereas a few others shared that cultural connections were not the focus of the discussion and that they would have 'to do more around this topic'. The different opinions amongst teachers about what culture is mirrors the ongoing scholarly debate about the degree to which science is socio cultural in its practice (Lee, 2005). The following quote, where a teacher elaborates that the laws of physics are universal speaks to this. This teacher said:

> "So that would be my, my, you know, biggest obstacle is how do I put the culture piece into all this? Because I know we wanna put culture in, but science to me is just like, <laugh>, it's just density is density, no matter where you come from <laugh>. But I guess, you know, you can have examples of different things, whether it's that or the periodic table or, or, you know, whatever I'm, I'm teaching about. So, there's always a different aspect or different piece." (Teacher 7, interview 6/14/22)

The quote expresses the teacher's desire to integrate culture into science education, but at the same time signals the need to think more deeply about the nature of science and the various cultural ways that scientists learn together.

Most teachers positioned themselves as being familiar with concept maps and/or having used variations of them, such as mental maps or an interactive concept book. One teacher shared that the popularity of using concept maps in the science classroom declined since the Next Generation Science Standards came out in 2013. Just a few teachers had minimal experiences with or even have not used concept maps before. As for students, teachers positioned them as either new to or familiar with concept maps depending on whether they had an opportunity to practice before beginning the challenge. Moreover, most teachers used an asset-based language approach to highlight students' strengths, such as the one teacher who described them as 'super easy to work with and eager to help each other out in group work'. A minority of educators used more deficit-based language, when talking about their club. One teacher, for example, described how challenging the concept maps activity was for the students as followed:

> "Having to do the, the concept [map] and trying to make associations, um, it was like for them, it was like a brick wall. Like they couldn't understand what we really wanted, and their connections were very limited. I think they didn't expand them. Whereas, you know, as adults, we're, it's a lot easier for us to make all those types of connections. But for them, especially with these two years [of COVID-19], like their processing time, what they determined to be

> adequate and what we determined to be adequate. We're talking about two different things." (Teacher 6, interview 6/10/22)

Also, teachers talk uncovered which role they took on and if they developed a sense of belonging. Most of the eight focal teachers used concept maps because it was presented as a requirement at the challenge and these teachers made no attempts to stay longer in this system than necessary. Whereas one teacher saw more value in an interactive concept book, which 'is a very interactive version of the same type of things that we do for a concept map' and that was used in the school where this teacher taught. Nevertheless, three teachers were very excited about the use of concept maps, an enthusiasm that went beyond the club setting and began to establish corresponding activities for the regular classroom, such as the one teacher who said:

> "[My co-teacher] and I weren't exactly sure how it was gonna be or how effective it was gonna be, but when they [researchers] came in and, and, uh, modeled it for us, we said, wow, that's very effective. So, we've been discussing how we might incorporate it into some of the lessons next year, because we've seen how it's done with, you know, the, um, with the weather and the events and, and how, you know, everything ties in together. Uh, so, you know, we'll probably do that for different units next year and just try it out." (Teacher 7, interview 6/14/22)

Summarizing, almost all teachers shared a more traditional understanding of concept maps. Most of them positioned themselves as being familiar with concept maps, but only half of the clubs had a chance to practice them before the actual challenge started. Educators mainly used an asset-based language when they talked

about their clubs and the activities they did. Yet, even if teachers got a better understanding about concept maps, just a few signaled the desire to use them in the future.

3.6.1.2 Researchers Figured World (RFG). Researchers shared a contemporary understanding about concept maps (Ettenauer et al., 2023a). They considered the maps as a tool that reveals more information about the person who constructed them that goes beyond conceptual understanding. Thus, students choose words purposefully to be understood by others and concepts are usually examples that have been experienced. One researcher, who used to work as a science teacher, described this new perspective as followed:

> "I see that concept maps actually hold all three types of information, but as science teachers, we have only, we tended to ignore two of them and only focus on one. And my hope with LaCuKnoS is we could expand that to use all three strands [knowledge, language, culture] and see what's in common. … We know that teachers do lots of amazing things that never get documented in research, right? So, I don't know, maybe people have done this, but it hasn't gotten disseminated. People haven't written about it or shared it. So, if they're doing it, they're doing it in their own classrooms and nobody else gets to learn from it. So hopefully we can share this approach and maybe this will prompt other teachers to go, oh, hey, I do that. You know, I just didn't like tell anybody about it." (Researcher 2, interview, 1/29/24)

Although researchers agreed with the new understanding of concept maps, which builds on shifts in research on learning (National Academies of Sciences,

Engineering, and Medicine [NASEM], 2018), the term ‘culture’ also evoked different meanings for them. The following quote, which deals with the idea that societies have different meanings when it comes to culture, came up during one of their discussions as the one researcher explained:

> “So, when I think of culture, it's more like art, paintings, music, we have a different word in [my home language] for culture. So, it always hit me [when I hear the English word], and I have a real issue with the [English] word culture. Now I got more familiar with it, and I have a different word [in my home language] for it. Not, [just] the one-on-one translation. I would rather use the word mentality instead.” (Researcher 1, recorded meeting 1/29/24)

Researchers positioned themselves as experienced working with concept maps either due to their work as science instructors or through collaboration in other research projects, where concept maps have been frequently used. Although the researchers were familiar with using concept maps, both were new to the analysis process of scoring concept maps across multiple strands, which was done using a holistic rubric. But over time, researchers became more and more experienced as they scored the maps for knowledge, language, and cultural connections. Heatmaps to represent frequency of codes were developed as well as rules to create student profiles to determine whether a proposition of a concept maps was close to the topic and purpose of the lesson or further away (see chapter 2). Researchers’ language was influenced by constructs and acronyms from Legitimation Code Theory (LCT) and its dimension Autonomy (Maton & Howard, 2018). For example, they used descriptors like ‘sovereign code’ or ‘PA+, RA-’ to describe if a concept is close to or further

away from the topic. Although the terms may seem somewhat disjointed to people unfamiliar with this theory, they made perfect sense within the researchers' figured world of concept mapping as the following quote shows:

> "And I think, let me see what I wrote for that club, if this is helpful for you. I just captured what I think it's the topic, the theme. Um, and, but what comes to my mind, I think we see if when I scored the maps, we see again, a lot of redundancy. But, um, so if I look at the student profiles, they are more dominant in the projected quadrant. That means that they have a PA+. So, they're on topic, but have a different purpose." (Researcher 1, recorded meeting 1/29/24)

Thus, researchers found LCT language helpful for analyzing concept maps in a non-judgmental way, compared to other holistic approaches that use a rubric to create poor, better, or best hierarchies. The researchers' figured world also accepted that students take ownership when constructing their maps and gave credit for most ideas student had. They rarely scored propositions as being unrelated, almost always seeing some connection that the students were attempting to make to the topic. Yet, it was difficult for researchers, since they were not in the clubs when most of the concept maps were produced, to distinguish things such as which words came from the students versus from the teacher, or which concepts were things that had actually been experienced by students rather than ideas that had been told to them by others. Bullet points or unfinished maps were the only indicators that students were unfamiliar with concept maps or did not have enough time to finish their product.

As the researchers spent more time analyzing concept maps over the past two years, they eventually gained a better understanding of their nature and became more drawn into the figured world of concept mapping. In other words, researchers developed a sense of belonging and expressed the wish to continue their scholarly work around concept maps. It is as the one researcher said when noticing that the end of the project approaches soon:

> "There is so much, that we haven't even touched yet because the analysis process was unexpectedly time intense. However, I wish we would have more time to dig in deeper with our analysis." (Researcher 1, memo 2/26/24)

Summarizing, researchers held a contemporary view about the role concept maps can play as identity artifacts. They positioned themselves as experienced with concept maps but had to rely on certain indicators to tell them whether students were familiar with the maps. Researchers used LCT language, which focuses more on the nature of the concept maps and offer a non-judgmental way to describe the clubs and the student's work. The intense analysis process resulted in researchers being drawn into the figured world of concept mapping and created a desire to continue with the analysis process.

3.6.2 Concept Maps Generate Evolving Views

Teachers' and researchers' narratives about the students' concept maps not only created multiple figured worlds but, more importantly, were perceived differently between and within these systems. Sometimes the content of the conversations overlapped, especially when it came to talking about club demographics or which natural disasters might or have occurred in the area where

clubs are located. Talk also elicited insider information that was not known in the other world, such as when teachers shared stories about what happened in their clubs during the concept map activity. Even if conversations brought forth various opinions, agents in both worlds could benefit from each other's thinking and in the best-case, came to see students work in a different light.

3.6.2.1 Views between Figured Worlds. Agents in the TFG and RFG perceived concept maps differently. Teachers, for example, valuated their students' work in many ways, such as by saying 'good job', 'there is more than I expected' or 'I see a lot of the same wording'. The latter expression came from a teacher who responded to the question of whether concept maps reflected the big ideas the teacher had when teaching the lesson. This teacher said:

> "I think that the kids used a lot of what was provided to them within the presentation and the lesson, but … [if] I would've handed them just a paper [that] says natural disasters, what do you think of this? I think the outcome would've been very different from your concept maps. … Because the reason I say that is because I see a lot of the same wording … I'm assuming they're all, whatever they remember from the lesson and trying to connect what they just learned." (Teacher 6, interview 6/10/22)

At the same time, the researchers reflected on their findings about the same club (see Figure 3.1) yet focusing more on patterns that came up for knowledge, language choices and experienced versus learned concepts. Comparing the two statements one thing stood out. Even if the teacher and the researcher noticed that students used the same verbiage to connect what they have learned in that lesson, they

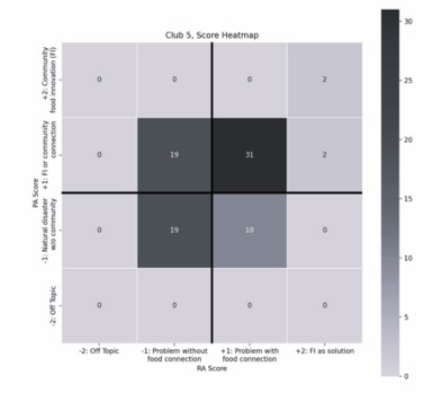
came up with various explanations of why that would be the case. The teacher referred back to the lesson and the information provided to explain why students used the same concepts. Researchers did not have this inside information, nor could they distinguish which words came from the students and which from the teacher. Yet, researchers listed several other indicators (e.g., word choices came mostly from students rather than from the template, mainly used learned concepts, the knowledge and culture two-in-one visuals show no extremes in the coordinate plane) that speaks to the nature of the concept maps. This example demonstrates that if researchers and teachers had the chance to exchange their information, they could both benefit from each other's thinking. Researchers, for example, could get a better understanding of which words came from the students, and which ones came up during the lesson. Teachers, on the other hand, could take the researchers' ideas and distinguish where word choices came from in order to expand the student's vocabulary.

Figure 3.1

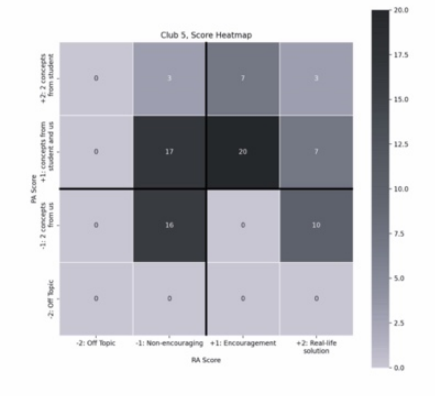
Researcher Notes

Notes 1/18/24 for club 5:

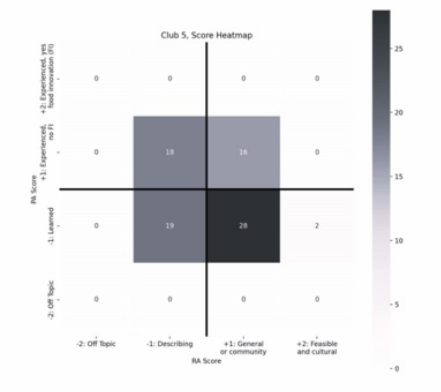
Knowledge



Language



Culture



- Noticed redundancy of concepts whilst scoring.
- Often used words: evacuation, farms, food insecurity, natural disaster, wildfire
- Knowledge: heterogenous pattern across club - more mix profiles, overall heatmap shows no extremes, stayed more in the middle of the coordinate plane.
- Language: 16% PA++ or 53% PA+ - most words came from students, either mix or sovereign dominant
- Culture: used mainly learned concepts (PA-) to talk generally about problem solving (RA-), almost no extremes like knowledge scores.

3.6.2.2 Views Within Figured Worlds. Views about concept maps can also differ within one figured world. For example, two teachers who co-taught the same lesson in the same club expressed different opinions when asked if concept maps give their students an opportunity to make connections to personal interests, the community they live in or their culture. These teachers said:

> "I do think they could be used for that. I think that if we had, um, had them do another concept map, maybe about the, uh, recipes that they had created, we would've seen some of that. Cause I know there was a lot of cultural representation in the recipes themselves with things like dried elk and tacos … (Teacher 5, interview 6/6/22)

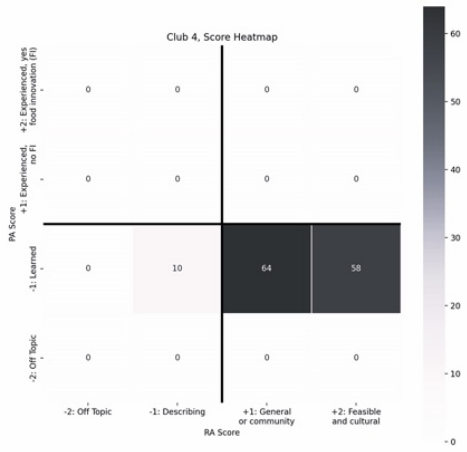
> "Yeah, I think as (name of teacher 5) talked about with like the elk and cultural, um, foods there, but also, um, food goes across all cultures. So, I think that was kind of a cool thing to, um, to talk about like kimchi and other, other things there too. So, I think it, it, it did, and I think it could be a valuable tool for that sort of thing. (Teacher 4, interview 6/6/22)

Even if the two educators agreed that concept maps could be used to see these cultural connections, not all of them can see such connections in the maps their student created. Teacher four acknowledged that the concept maps actually did already connect to personal interests, or the community students live in because 'food goes across all cultures.' Whereas educator five argued that this was not the case, but instead suggested to do another map that focuses on culture. In contrast, researchers noted that students mainly used learned concepts, such as canning or salting, to solve

the problem of food innovation (see Figure 3.2). Although researchers had to make assumptions, such as if younger students were already familiar with methods like salting or canning, in order to decide if concepts were learned in school or might have been experienced outside of school, their findings could be helpful for teachers. For example, teachers could encourage and give explicit examples to students for how to incorporate more concepts based on their lived experiences beyond school into their work by making clearer the connections between what was learned at home and its application in the school context.

Figure 3.2

Researcher Notes

Club 4: Cultural Scores	
	Thoughts are all around FI, mainly methods (e.g., canning, salting, drying). There is an introjected trend (PA-, RA+), either introjected-only or introjected-dominant. Most propositions (64) are associated/ ancillary (PA-, RA+), second most (58) are associated/core (PA-, RA++). Students used mainly learned concepts (PA-) to either mention something that solves a problem or is connected to community (RA+) or to propose a feasible and culturally connected solution (RA++).

3.6.3 Figured Worlds of New Perspectives

Students were positioned through their work in the TFG and RFG. Researchers, who have not met the students, used LCT language to determine if a student displayed, for example, a sovereign-dominant profile meaning that 50% or more of the propositions were on topic and on purpose. Whereas teachers had already

established a relationship with students through their work in the science clubs and positioned them based on their shared history at least as much as they based their ideas on the actual concept maps. They described students as ‘always very creative’ or ‘struggled to actually write things down on the map’. However, it was LaDousa and Baldrige (2017) who reminded us to be mindful when positioning others, as these images could be adopted by participants who have less power in these systems, such as students in schools. Since figured worlds are constantly changing through people’s day-to-day activities, these systems potentially have the power to shift people’s thinking and thereby to reposition actors as the following example shows.

One teacher had the club work in two teams that came up with different ideas and experiences when discussing food insecurity. These students were described as having hardly experienced any natural disasters and therefore having a hard time to imagine that, for example, stores would be closed in an emergency. When asked how the students responded to the concept map activity this teacher described the two teams as followed:

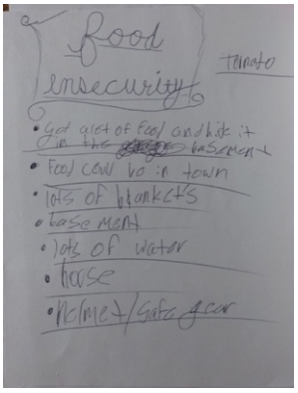
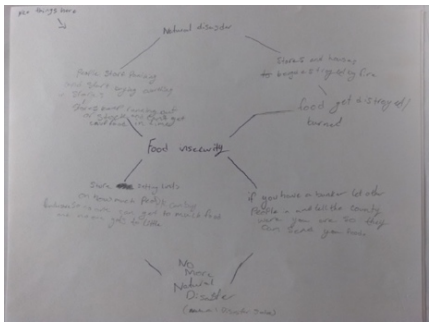
> “Um, they were very, they're very interested in, um, especially [team 1] was very interested in once they understood what food insecurity was, is kind of how to solve that problem and what if that actually did happen. Whereas [team 2] was a little bit checked out with that, um, [team 1], uh, once they kind of understood what we were doing they had really good ideas on how to solve a problem, and that was good to see.” (Teacher 3, interview 6/3/22)

In the passage the teacher described the two teams as – ‘interested’ versus ‘a little bit checked out with that’ – which led to the assumption that it was easier for team one to

carry out the activity because in the end they ‘had really good ideas.’ However, even though team one only turned in a bullet point list rather than a concept map according to the researcher’s notes (see Figure 3.3), their scoring showed that both teams performed almost equally well in regard to the knowledge they expressed. In order to approach the topic of food insecurity, both teams applied concepts that were somehow related to the topic. Although team two used more non-pregiven words in their maps, team one came up with additional solutions about how to solve the problem of food insecurity. Thus, if the teacher and the researcher had the chance to exchange information, the teacher could potentially see the overall performance of the teams in a different light. This information could help the teacher to focus more on the idea of problem solving and how to accomplish this. Moreover, the opportunity for a change of perspective that this example opens up is important because it shows how objectivity and subjectivity can complement each other in exploring students’ science sense making and communication.

Figure 3.3

Researcher Notes

Club 3	Team 1	Team 2
Concept maps		
Construction	Bullet points – just a list of ideas	lines, no bubbles, difficult to distinguish concepts & links
Impression	The lines between the words distinguish ideas, topic is nicely decorated	Reads like an emergency plan, funny (nice things here) and caring (what to do if)
Knowledge scores:	Introjected-Dominant 7 PA-, RA+	Introjected-Dominant 8 PA-, RA+
Teamwork makes it hard to distinguish who had which thought, food seems important, both have same profile, concepts pursue a different topic, are related to food and somehow related to the topic.		
Language scores:	50:50 P and S P: 4 PA+, RA- S: 1 PA+, RA+ S: 4 PA+, RA++	Projected-Dominant 2 PA++, RA- 4 PA+, RA-
Maps lean towards projected scores, meaning that students used a mix of non-pregiven words and words from the template (PA+) to describe something (RA-). Team 1 proposed solutions (RA++) and/or encouraged for action (RA+). Team 2 used non-pregiven words only (PA++)		
Culture scores	50:50 E and I I: 4 PA-, RA+ E: 4 PA-, RA-	Exotic Dominant 6 PA-, RA-
Maps lean towards exotic scores, meaning that concepts are learned (PA-) and unrelated to problem solving (RA-). Both used learned concepts (PA-), Team 1 has 4 RA+ = generally about problem solving, whereas RA- = unrelated to problem solving. Team 1 had suggestions to solve a problem.		
Overall: Concept maps show small differences in how to tackle the topic • Kn concepts are related to food and somehow related to the topic (PA-). • La team 2 came up with non-pregiven words (PA++), team 1 had practical real life solutions (RA++) and/or encouraged that something needs to be done (RA+) • Cu only learned concepts (PA-), team 1 had suggestions for problem solving (RA+)		

3.7 Discussion

This study was designed to answer the following research question: How does thinking about concept maps help teachers figure about supporting their student's science sense making? Findings showed that concept maps in their function as identity artifacts created two figured worlds. Teachers and researchers as main actors in these as-if worlds had different histories with and understanding about concept maps causing them to position themselves and the students' work within these systems. Some participants, especially the researchers, became quite passionate and found their role in the figured world of concept mapping. Teachers profited from real life relationships with the students, which filled their world with emotions and shared memories. In contrast, the use of LCT language enabled the researchers to perceive the students work from a different, perhaps more distant perspective, as the focus was the nature of the concept maps. Even if the TFG and RFG had similar characteristics, they mainly differed in their thinking about the students' maps. Teachers shared a more conventional understanding about the role of concept maps whereas researchers considered them to be contemporary because they hold various types of multimodal information. The researchers also assumed that concept maps are being used more often in science education than was actually the case. Findings also suggested that insider information in one world led to blind spots in the other, pointing to the need to exchange ideas to gain further insights. Even if maps were perceived differently between and within worlds, together teacher and researchers could co-construct knowledge for the students' benefit. And therein lies the significance of figured worlds. They might change people's perspectives through their day-to-day activities,

such as when teachers and researchers share their ideas, which in turn could create new systems of possibilities in which students' work is perceived differently. A shift in perspective is helpful for all but especially for students who already experience academic disadvantages.

3.7.1 Implications

Concept maps in their role as identity artifacts have meaning that goes beyond what a person knows about a topic. For example, they tell us how word choices can be made to position ourselves as competent knowers. As such, identity artifacts hold 'public character' (Subero, et al., 2018, p. 167) because they illustrate what is important for the student and other people, such as teachers or researchers, can recognize these ideas. However, these connections only become clearer through analysis, which can subsequently be used to link assets to respective learning goals such as content or practices. Therefore, concept maps have educational value as they may help teachers to build on pre-existing skills and strengths students bring to the classroom. Furthermore, once educators become familiar with the specific features of concept maps, they will realize that there is no right or wrong way of doing them, but that this tool offers limitless opportunities to make it your own.

Another key suggestion that came from these findings was that the two worlds – TFG and RFG - should share their results in order to benefit from each other's expertise. The topic of bringing things together in education is not new. In 1959 Snow (2012), for example, argued that science and art became two cultures because they had not much in common. Sixty years later Massey (2019) stated that the two have grown closer, such as through collaborative research. A similar trend is noticeable in

education where teachers and researchers build partnerships, gain a shared understanding and co-construct new knowledge through collaborative research (McNae & Cowie, 2017). Yet, as this type of research is time and personnel intensive, new ways are needed to overcome this limitation. More recent research, such as the LaCuKnoS project (Buxton et al., 2022) uses, for example, professional development to obtain feedback from teachers on lesson design, creating space for these world-bridging conversations.

3.7.2 Limitations

A limitation of this study is that the students' voices are only represented through their concept maps. Even if they are powerful instruments that speak to the students' identity, additional interviews, or think alouds with the students would provide further information about their intentions and thoughts as to why they constructed the concept maps the way they did. Another limitation, as described earlier in this paper, was that no participating teacher functioned as co-author. Yet, moving forward with the LaCuKnoS project it is intended to introduce the concept map analysis to participating teachers, so they are able to provide feedback. Overall, since the effects of identity artifacts on science teaching and learning are understudied, additional empirical research addressing identity artifacts in science education other than using concept maps would be beneficial for this body of research.

3.7.3 Conclusion

Figured worlds theory can help demonstrate how identity artifacts generate opposing opinions about the person who created them but also show ways that

people's thinking can be changed through information exchange. Thus, it is argued that concept maps should return to more frequent use in science education because they show important information about the students and what has significance for them. However, this should not be a one-way road because teachers and researchers can learn from each other's expertise for the student's benefit. Yet, because concept maps analysis using LCT autonomy codes is time and labor intense, and therefore not practical for busy teachers, here are a few indicators that educators could use to quickly evaluate maps from a more contemporary perspective: (a) check for word examples that came up from the class discussion, which helps to differentiate between student's own word choices and already learned vocabulary to expand their language literacy; (b) distinguish between learned and directly experienced concepts to help to connect teaching with the student's interests, their family and community funds of knowledge; (c) evaluate how close or further away concepts are from the lesson main topic to get an idea about which areas needs re-teaching. Finally, as one participating teacher suggested educators can help students to move away from the idea that their work is just about doing things right, but rather assist them to understand the value of doing such conceptual work. There are many small but effective changes that can be made in the process of how to optimize teaching and learning. The use of identity artifacts in science education is one of them.

4. Conclusion

Concept maps are graphic organizers that visually present how concepts relate to each other (Novak, 1998), but have traditionally been used to study what a person knows about a topic (Chou et al., 2022). Yet, knowing that learning is socio-cultural, and that the learner embodies these stimuli (NASEM, 2018), one might wonder whether concept maps reflect these socio-cultural influences. This is valuable information for educators, for example, because knowing what assets to build on is a key aspect of a high-quality education (Gitschthaler et al., 2022). However, one finding of this dissertation was to show that these connections only become clearer through analysis, as they are difficult to recognize through mere observation alone, as illustrated by the mini cases in chapter two. The insights gained from the analysis can then be used to link students' knowledge assets to respective learning objectives such as standards or practices.

Thus, this study examined concept maps from a contemporary perspective to demonstrate that they hold more information than just conceptual understanding. Findings suggested a new framework for supporting all, but especially multilingual students, and offered a new application of the term identity artifacts (Subero et al., 2018) that meets the new understanding of concept maps. This study also highlighted how teachers and researchers can benefit from each other's expertise to develop a shared understanding of how to best support students. Although their concept maps provided evidence that students made flexible word choices that suited their communication purposes to show what they knew about a topic, the maps merely hinted at explicit cultural connections, such as through the use of home language,

culturally relevant examples, or artistic representation. Without more data, there was not enough evidence to make stronger claims about what concept maps can reveal about the cultural and community connections that students make.

Next, the findings from each article are summarized before I compare the results of the analysis from the total of nine participating clubs in this dissertation. Information from teacher interviews is used as well for the analysis at the club level. Finally, I will share my thoughts about the frameworks used, point to overarching limitations, and offer recommendations for teacher and future research.

4.1 Article One

This article examined if concept maps actually hold more information than conceptual understanding only and tested if LCT Autonomy is a feasible approach to score data for multiple purposes to answer this research question: How do elementary students' concept maps from a multilingual after school science club reflect their sense making during a science lesson in ways that support students' (a) science knowledge building for informed decision making; (b) language development for science communication; and (c) cultural and community connections to science. Two theories were used to analyze concept maps - the LaCuKnoS model (Buxton et al., 2022) and LCT autonomy codes (Maton & Howard, 2018). To give an example, only one multilingual elementary club with thirteen students was selected for this paper from the total of 20 participating after school science clubs.

Findings of this mixed methods study showed that students took on agency to decide which concepts will be part of their map and which not. Moreover, the use of different modalities and translanguaging suited the students' communication purpose

to position themselves as competent knowers. They also brought in concepts based on lived experiences, such as an ice storm that happened in the area, they live in. However, even if there was evidence that pointed to at least some explicit cultural connections, such as the use of translanguaging or art, further information is needed from the students to make claims about cultural connections. Finally, mini cases illustrated the value of coding by pointing to maps that appeared similar at first glance but had different profiles, or vice versa. Also, the idea of a three-strand tour was created to suggest that thoughts need to journey into and through multiple quadrants of the autonomy plane to help the learner understand and make connections.

4.2 Article Two

The second article studied how teachers in particular can use concept maps as a tool to support their teaching and students' learning and as such aimed to answer the following research question: How does thinking about concept maps help teachers figure about supporting their student's science sense-making? Subero et al.'s (2018) term of identity artifact fit best to describe the contemporary perspective of concept maps, because they show what has meaning to the students, which is in turn valuable information for teachers to adapt their teaching and build on assets students bring to the classroom. Holland et al.'s (1998) figured world theory helped analyze ten teacher interviews and researcher data on eight clubs with which educators worked.

Findings of this qualitative study showed that concept maps created two figured worlds in which maps were perceived differently by teachers and researchers. Teachers profited from real life relationships with the students, which filled their world with emotions and shared memories. Instead, the use of LCT language enabled

researchers to perceive the students work from a different perspective, as the focus was more on the nature of the concept maps that on the students who created them. Insider information in one world led to blind spots in the other but at the same time could be helpful for the other to gain further insights that in turn could create new systems of possibilities in which students' work is perceived differently. A shift in perspective could be helpful for all but especially for students at risk who may sometimes be viewed through a deficit lens.

4.3 Findings at the Club Level

In section 1.2.1 I described the decision-making process that influenced the sampling of the nine clubs that were used for article one and two. In this chapter I want to look across these clubs, because at the time I wrote the first article, I had only one club to fully analyzed, which got the pseudonym 'Curious Minds.' I subsequently scored a total of 86 concept maps which were constructed by 91 students from three elementary (ES), four middle school (MS), and two high school clubs (HS) with one club working in two teams (see Table 4.1). As I looked at the student profiles in these clubs, I noticed that in addition to what I found in the first article, where there were similar student profiles within one strand, there was another pattern that became visible across the three strands, as explained in (b) and (c).

(a) The Curious Minds Club, as well as students from Club One and Club Three showed a consistent pattern within one strand meaning that most or all of the individual profiles are in one of the four quadrants of the autonomy plane. Club Three, for example, had 100% of the knowledge scores in the introjected quadrant, meaning that concepts pursued a different topic which was unrelated to community

food innovation (PA-), but was related to food (RA+). Yet, looking across grades[15], knowledge scores for the three elementary clubs are mainly sovereign (PA+, RA+), whereas secondary grades are not. This is explainable because younger students stayed more directly focused on the central topic of communal food innovation whereas secondary grades students were more likely to take detours and attended to a broader range of issues caused by natural disaster and/or food insecurity, which is mirrored in the scores of their concept maps.

(b) Most students from Club Four, Club Seven, and Club Eight showed similar patterns across the three strands with just a few outliers. For example, five out of seven students from Club Eight showed a projected dominant knowledge, sovereign dominant language, and a mixed culture pattern. This indicates that knowledge-wise concepts were on topic without attempt for a solution (PA+, RA-), word choices were mostly student-generated words [not from the activity word bank] (PA+) and were used to encourage that something needs to be done (RA+), whilst referring to learned and experienced concepts. Finding the same pattern across all strands within a given club seems to imply that even if maps are organized differently, students had many of the same propositions. This raised the question of how much agency students had to make their own maps or if in some clubs, students may have closely followed teacher guidance. Teachers provided more insight into how the concept map activity was carried out in different clubs. Some shared that their clubs ‘crowdsourced and figured out together’, did ‘a brainstorm activity like a

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[15] For more detailed information see Appendix L.

group shout out', or showed an expert map under the document camera. Thus, findings show that the way the activity was supported influenced the outcome seen in the maps.

(c) Finally, Club Two, Club Five and Club Six displayed a heterogenous pattern across all strands, meaning that the student's profiles within the clubs were diverse and made it impossible to come up with a tendency. The heterogenous student profiles led to the assumption that students in these clubs were given more freedom to use whatever they thought necessary to construct their concept maps. These findings were also supported by teacher interviews because, unlike the clubs described before, this group teachers allowed students take on agency, as the following excerpts from the interviews show. Teachers shared that the students worked like 'investigators or detectives who knew what to do', 'teachers' stepped back and allowed [things] to happen', or students got 'priorities for what they thought was most important to focus on.' Thus, whether students in these clubs had practiced how to construct concept maps (Club 2) or were coming unexperienced into this activity (Clubs 5 and 6) these teachers gave autonomy to their students.

Overall, findings at the club level seem to support what Reiska et al. (2018) articulated, namely that concept maps reflect the conditions under which they were constructed. They also indicate that teachers made their own choices about how to facilitate the concept map activity, even if the overall structure was somewhat determined by the challenge. For example, educators were free to decide if they wanted to practice doing concept maps before the actual challenge started and whether they wanted to show an expert map to the students. Moreover, teachers seem

to value that the LaCuKnoS project does not require them to implement lessons in one particular way, but rather they were free to choose how to best to support their students (Buxton et al., 2015). However, even if choices teachers made were equally good, I would suggest giving students more agency so they can think outside the box and decide how to make concept maps their own.

Overall, moving along with the LaCuKnoS project it will be interesting to compare and contrast these findings with the other student profiles from the 2022 challenge to see if they also followed these three patterns that were encountered. Additionally, it will be compelling to compare results of the 2022 challenge with those of the 2023 challenge, where researchers facilitated the concept map activity, to see how prompts from different instructors' influence student's work.

Table 4.1

Student Profiles at the Club Level

Club	Knowledge	Language	Culture
Club 1: 5 students	Heterogeneous	Exotic/Projected	Exotic/Sovereign
Club 2: 4 Students	Heterogeneous	Heterogeneous	Heterogeneous
Club 3: 7 students	100% of the scores are introjected dominant	Most scores are projected	Most scores are exotic
Club 4: 15 Students	93% of the students showed the same pattern across three strands with one student as an outlier.		
Club 5: 9 Students	Heterogeneous	Heterogeneous	Heterogeneous
Club 6: 9 Students	Heterogeneous	Heterogeneous	Heterogeneous
Club 7: 15 Students	73% of the students showed the same pattern across three strands with six students as outlier.		
Club 8: 7 Students	71% of the students showed the same pattern across three strands with two students as outlier.		
Curious Minds Club: 13 Students	100% of the scores are sovereign	Heterogeneous	69% of the students scored sovereign.

4.4 Thoughts about Frameworks

I used several theoretical frameworks for this study – the LaCuKnoS model (Buxton et al., 2022), LCT autonomy codes (Maton & Howard, 2018) and Holland et al.'s figured worlds theory (1998). In the following I would like to briefly share my thoughts about these frameworks. However, my reflection on the LCT autonomy codes are a little more detailed as I spend a lot of time coding the propositions and thinking about how to present the results from them.

4.4.1 The LaCuKnoS Model

The LaCuKnoS model (Buxton et al., 2022) resulted from a previous research project, which studied how secondary science teachers can support the growing numbers of multilingual students in middle school and high school classrooms (Buxton et al., 2017). Thus, the LaCuKnoS model builds on three theories that guides the three strands. The language and culture strands used the same theories from this previous project. For example, the language strand built on Halliday's (2004) systemic functional linguistics (SFL), which is already a very solid model. Same is true for the culture strand, which built on years of experience of Paris's (2012) work using cultural sustaining pedagogy (CSP). In contrast, the knowledge strand was based on the Next Generation Science Standards (National Research Council, 2012; NGSS Lead States, 2013) but without a clear supporting theory about knowledge behind it. Thus, for the LaCuKnoS model, it was decided to try using the ideas from Maton's LCT (2013) and how they could be applied.

4.4.2 Figured Worlds Theory

Figured worlds theory (Holland et al., 1998) is a model that, at least in my experience, portrays systems of complexity in an easy-to-understand way. Although it is kind of vague and has been inconsistently applied by researchers to socio cultural issues in education (Urrieta, 2017), which makes it harder to compare findings, it gives participants a voice to express their thinking and mirrors their understanding about these as-if worlds. Yet, it's real significance lies in the idea that systems are dynamic and therefore have the ability to change. Thus, people have the power to change something through their day-to-day activities. This is especially important,

because sometimes people feel restricted in their actions and by the systems they interact with, such as by schools, but even if changes in figured worlds might seem small, they are meaningful.

4.4.3 LCT Autonomy Codes

I especially liked the central premise of LCT autonomy codes that content and purpose of a learning interaction are connected because it took the emotion out of the analysis process and allowed me to focus more on the nature of concept maps. Even if scores reduced the richness that I saw in the concept maps, such as when students used emojis or drawings to make their thinking visible, the PA, RA combinations enabled me to take on a more objective stance. Moreover, frequency counts on the coordinate plane allowed me to describe in a non-judgmental way the nature of the maps compared to the poor- better, or best hierarchies' other rubrics usually create. Reducing content to points in the coordinate plane forced me to think about ways how to bring back the richness of the data, such as using art or heatmaps to portray findings.

One of the biggest obstacles I had was that I could not show LCT autonomy tours – a central feature of other research that has used this theory – because of the missing information about which concept came first, and which one was next. Yet, now as I think back, that was not as bad as I thought it would be. Instead, it forced me to come up with other ways to describe what was in the data, such as creating student profiles or the three-strand-tour. However, as I had the chance to take notes during the 2023 challenge, which allowed me to do autonomy tours for three secondary students, I now realize that the tools I developed to describe the findings might be more

sufficient or even equally helpful, particularly if scores stay just in one quadrant of the autonomy plane.

Usually, LCT autonomy codes have been used for larger datasets than found in concept maps, such as essays (Jackson, 2021) or video transcripts (Zhao, 2023). The decision to use larger data sets perfectly make sense now to me because reducing data to numbers, which are placed on the autonomy plane inevitably bring with it questions, which could be answered by looking at supporting data. This is important because concepts alone left room for questions, which could not always be explained rationally, such as did this non-pre-given word actually came from the student, from peers if they are working together, or from the teacher. Thus, I think it is helpful to have additional data sources, such as interviews or the option to ask-follow up questions, that accompanies the data set for it to be most conducive to LCT analysis.

Summarizing, I think that LCT autonomy codes, while a viable tool for analyzing data for multiple purposes, may not always be suitable for all topics and most likely require additional data, such as interviews or think alouds, to support the evidence that was found in data that uses less words, such as concept maps do.

4.5 Limitations

I recently facilitated a concept map activity for elementary students about artificial intelligence, where I took the time to engage students in conversations about why they used concepts like ‘video games’ or ‘Facebook’. And there it became clear that follow up questions or think alouds are tools that make concept map analysis complete. Moreover, I noticed that if we ask the right questions, we will probably get enough evidence to prove that concept maps also provide links to the students’

culture, their community, and interests. It is already there but we have to get more information to understand the meaning behind a concept. Thus, considering what I have learned throughout this project and looking back at the limitations I mentioned already in chapter one I want to highlight again the importance of having access to additional information that explains why the student chose one concept over the other and what was the thinking behind.

4.6 Recommendations

Although I have already mentioned recommendations for educators and researchers in the individual articles, I would like to summarize them and mention some additions.

4.6.1 Recommendations for Future Research

LCT autonomy analysis applied to concept maps requires additional data, such as interviews to support the evidence found in the maps, which raised follow up questions. As far as for culture, for example, there was some evidence in the data, such as translanguaging or the use of art, which hinted at cultural connections, but this was not enough to make a general claim. Thus, it is recommended to divide up the bigger topic ‘culture’ into sub-topics that guides the follow up questions researchers have for students to get a better understanding about the cultural component in the data.

One of the major recommendations would be to find ways to automate scoring for LCT autonomy codes, as this is time and labor intense. These are all resources teachers do not have in their already busy time schedules. However, if we want to emphasize the importance of contemporary perspectives, we should provide access to

tools that facilitate this new understanding. Rapid advances in artificial intelligence could help with this. For example, recently I went to a poster presentation at a science conference where some researchers used artificial intelligence guided programs such as SBERT to code data. This is, among other things, one idea to think more about how scoring can be automated, which could be tested through future research.

4.6.2 Recommendations for Educators

Concept maps allow students to show what has meaning to them. Even though it might not be the right tool for all learners it allows students to use whatever they think is necessary to show their thinking about a topic. One of the most compelling arguments that speaks for the use of concept maps is that there is no right or wrong way to create them. In fact, it is as the one teacher suggested that educators should more emphasize the 'point of doing' versus 'Am I doing it right'. This teacher said:

> 'Sometimes the kids are very focused on, am I doing this right versus like, uh, versus like, uh, what is the point of doing this? Like, what are you doing? Like, why are you doing it? There's for this particular thing, there's no right or wrong, it's just how are you relating to yourself to the concept map.' (Teacher 10, interview 10/24/22)

Thus, I would like to encourage teachers to make these connections explicit and thereby give students more agency to show what is meaningful to them.

However, in order to be able to draw connections between the student and the concept map a minimum of analysis is needed as these links are not always visible at first. For example, teachers could start by looking for concepts that students purposefully chose or even omitted. This is valuable information for teachers to

personalize their teaching because they then can, for example, integrate personal interests to increase motivation for learning or focus on topics that needed re-teaching. It is up to the teacher to make these things more explicit so students would look to make personal connections more intentionally. But that would also mean that concept maps will be used more often in science education as they are used now. I mention this because it seemed that most of the participating teachers did not use concept maps. Yet, the minority of them who were convinced that the use of concept maps has value for their students shared 'that they [students] were at least thinking kind of deeper and not just writing words by random', and that 'kids were more engaged trying to figure out how to connect the words.' One teacher also reported that the students said, 'Now we need to think what we're doing.' Thus, I hope that the outcome of this study will inspire educators to use concept maps more often in their classrooms.

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Appendices

Appendix A: Glossary

Term	Definition
Autonomy	Autonomy is one dimension of LCT and portrays the relationship between the content (PA) and purpose (RA) of a learning interaction (Maton & Howard, 2018).
Autonomy codes	Autonomy codes are combinations of PA (positional autonomy) that deals with WHAT is taught and RA (relational autonomy) that refers to the purpose WHY the content is meant to be learned (Maton & Howard, 2018).
Autonomy plane	Is another name for a coordinate plane where PA and RA combinations are visually placed into four quadrants. They are called sovereign, projected, introjected and exotic depending upon how close (+) or further away (-) they are from the target (Maton & Howard, 2018).
Challenge	The pre-college program annual event where students from all clubs come together to work on a STEAM problem. The 2022 challenge took place at the local schools due to COVID-19.
Concept Maps	Concept maps are graphical organizers that present multiple relationships between concepts (Oliver, 2009).
Exotic Code (PA-, RA-)	Data is off topic (PA-) and off purpose (RA-) (Maton & Howard, 2018).
Figured worlds	Figured worlds are 'socially and culturally constructed realm of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others' (Holland et al., 1998, p. 52).
Heatmaps	Heatmaps display the frequency of autonomy codes and the relationship between PA and RA for each of the three strands.
Identity Artifacts	Identity artifacts are 'productions based on the experience people have of themselves – including whatever is meaningful for that person (people, objects, activities, spaces, institutions, etc.) – which also require, in order to be made, the application of curricular content or competencies.' (Subero et al., 2018, p. 163)
Introjected Code (PA-, RA+)	Data is off topic (PA-) but on purpose (RA+) (Maton & Howard, 2018).
LaCuKnoS model	Instructional model for multilingual science sense making that builds on the premise that language, culture, and knowledge are interwoven and influence students' science sense making (Buxton et al., 2022).

Term	Definition
LaCuKnoS project	Is an NSF funded project, short for Language, Culture, and Knowledge building through Science. This research project supports teachers in enacting modern perspectives on science learning (Buxton et al., 2022).
Legitimation Code Theory (LCT)	Multi-dimensional framework that aims to reveal shifts in knowledge practices (Maton, 2013).
PA and RA combinations	Combinations are strong or 'autonomous' when close to the target (+) and can be found in the plus quadrants of the autonomy plane. They are weak or 'heteronomous' when further away from the target (-) and can be found in the minus quadrants of the autonomy plane. (Maton & Howard, 2018).
Principal investor (PI)	Leader of a research project.
Projected Code (PA+, RA-)	Data is on topic (PA+) but has a different purpose (RA-) (Maton & Howard, 2018, 2020).
Proposition	In a concept map, two concepts that are linked together with a line or arrow that shows a word/phrase that best describes the relationship between the two.
Sovereign Code (PA+, RA+)	Data is on topic (PA+) and on purpose (RA+) (Maton & Howard, 2018).
Student profiles	A set of rules that describe student patterns that became visible when analysing the two-in-one images, such as sovereign dominant or projected left out.
Three strands	Knowledge, language, and culture.
Translation device	Is a holistic rubric to score PA and RA on up to three levels. This study uses a level two translation device, which is less complex than the third level but more precises than the first level one.
Two-in-one images or visuals	Integrated heatmaps in the autonomy plane.

Appendix B: Translation Devices

Knowledge Building

PA: Community Food Innovation (CFI)			
PA	*Coding Categories*	*Description of Coded Content*	*Examples from Data*
+	PA++ (core)	Needs to be about CFI, has to have FI AND community connection	Canning (either cooking method or canned food)
↕	PA+ (ancillary)	Needs to be either about FI OR community connection	Connection to nutritious, livestock, hunger.
↕	PA- (associated)	Natural disaster without sense of community. NEITHER community NOR FI, related about food and somehow related to the topic.	Food insecurity – no rain
-	PA - - (unassociated)	Unrelated to the topic or something exotic.	Hanging links, empty bubbles, illegible words, relation does not make sense (e.g., FI – FI).

RA: Improve or solve food insecurity through food innovation (FI)			
RA	*Coding Categories*	*Description of Coded Content*	*Examples from Data*
+	RA++ (core)	FI as a solution to food insecurity	Food insecurity – Ramen
↕	RA+ (ancillary)	If is clearly describing something about food but not proposing a community solution. The word connects with food, even if it is describing a problem.	Connected to food: farm, starvation, livestock, seed, corps, hunger, indoor gardens.
↕	RA- (associated)	Talking about a problem, but concepts/word are not connected to food. No attempt for a solution.	Disasters - Droughts
-	RA - - (unassociated)	Some other reasons why they talk about natural disasters or something exotic.	Hanging links, empty bubbles, illegible words, relation does not make sense (e.g., FI – FI).

Language

PA: Content is what language does. Such as order a meal in Spanish, interact with people; use language to help communicate ideas. Adding ideas beyond that was given by the lesson we provided or by the teacher.			
PA	*Coding Categories*	*Description of Coded Content*	*Examples from Data*
+	PA++ (core)	2 concepts come from the student and NOT from us (either accompanying sheet or Barbara's concept map).	
↕	PA+ (ancillary)	One concept is from us (either accompanying sheet or Barbara's concept map) AND one concept comes from the student.	FI – ideas (FI is from us, ideas from the student)
↕	PA- (associated)	2 concepts are from us (either accompanying sheet or Barbara's concept map)	FI and Food insecurity.
-	PA - - (unassociated)	Off topic, not relevant, or something exotic. Note, if scoring for knowledge is exotic, that does not necessarily affect language scores.	Examples for exotic codes: hanging links, empty bubbles, illegible words, relation does not make sense (e.g., FI – FI).

RA: Purpose is to make language choices, to be understood. Concept that encourages for action			
RA	*Coding Categories*	*Description of Coded Content*	*Examples from Data*
+	RA++ (core)	Is about practical real-life solution.	Examples of shelf stable food, Preserve, canned foods.
↕	RA+ (ancillary)	Encouragement but does not lead to action, kind of vague something needs to be done.	Food ideas, food insecurity, nutritious – kind of vague, talk about something positive.
↕	RA- (associated)	Non-encouraging, it is not clear that there is action, just describing	
-	RA - - (unassociated)	Off topic, not relevant, or something exotic. Note, if scoring for knowledge is exotic, that does not necessarily affect language scores.	Examples for exotic codes: hanging links, empty bubbles, illegible words, relation does not make sense (e.g., FI – FI).

Culture

PA: Idea of cultural Knowledge. Do we see specific connections between food and culture based on directly versus hypothetical experienced?			
PA	*Coding Categories*	*Description of Coded Content*	*Examples from Data (club 32)*
+	PA++ (core)	Student's actual experience AND concept is about food innovation.	Ramen, canned corn
↕	PA+ (ancillary)	Based on actual student's experience but without communal food innovation.	Ice storm, drought, wildfire, flooding, smoke, camping related
↕	PA- (associated)	Something students learned but not experienced. Still could be about food.	Healthy candy cane, earthquake, volcanoes.
-	PA - - (unassociated)	Off topic, not relevant, or something exotic. Note, if scoring for knowledge or language is exotic, that does not necessarily affect cultural scores.	Examples for exotic codes: hanging links, empty bubbles, illegible words, relation does not make sense (e.g., FI – FI).

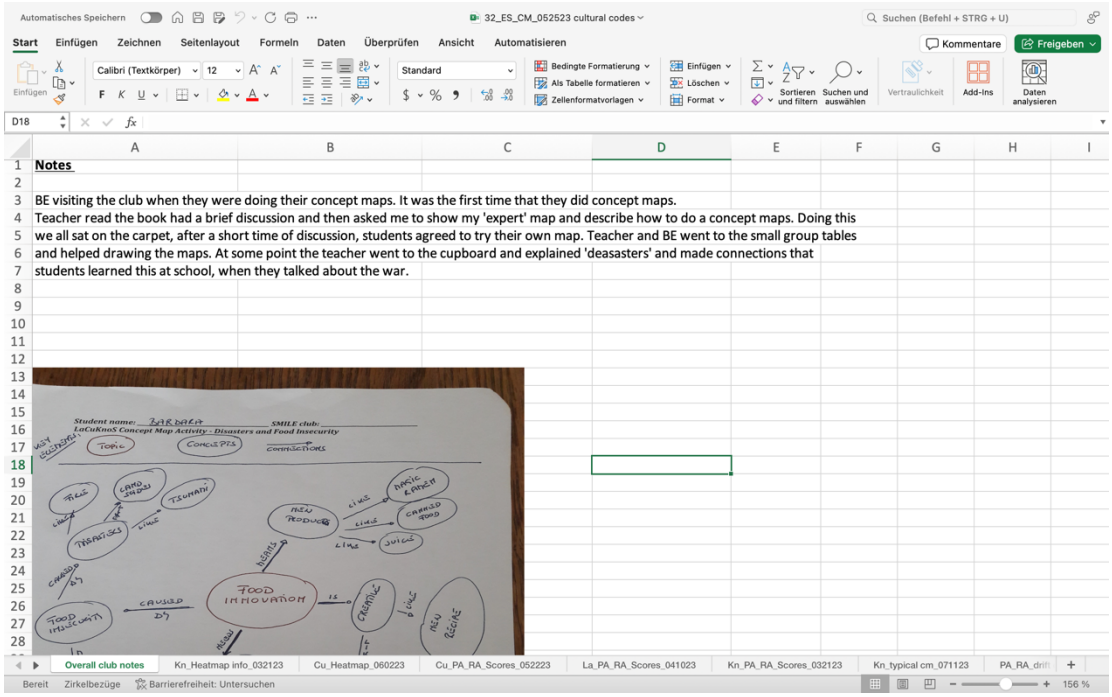
RA: Purpose is how to solve a problem.			
RA	*Coding Categories*	*Description of Coded Content*	*Examples from Data (club 32)*
+	RA++ (core)	Problem solving recognizes social resources, is a feasible solution AND is clearly culturally connected.	FI points/implies to a solution Examples: Ramen, canned corn; my family who lives at the coast always did smoke fish
↕	RA+ (ancillary)	No connection to community, more generally solves that problem. OR is connected to community but no clear problem solution.	Food Innovation – ice storm, Food Innovation – food insecurity Ideas - nutritious
↕	RA- (associated)	Unrelated to problem solving, more describing.	Disasters – floods Disasters – no energy Food Innovation - ideas
-	RA - - (unassociated)	Off topic, not relevant, or something exotic. Note, if scoring for knowledge and language is exotic, that does not necessarily affect culture scores.	Examples for exotic codes: hanging links, empty bubbles, illegible words, relation does not make sense (e.g., FI – FI).

Appendix C: Concept Map Analysis

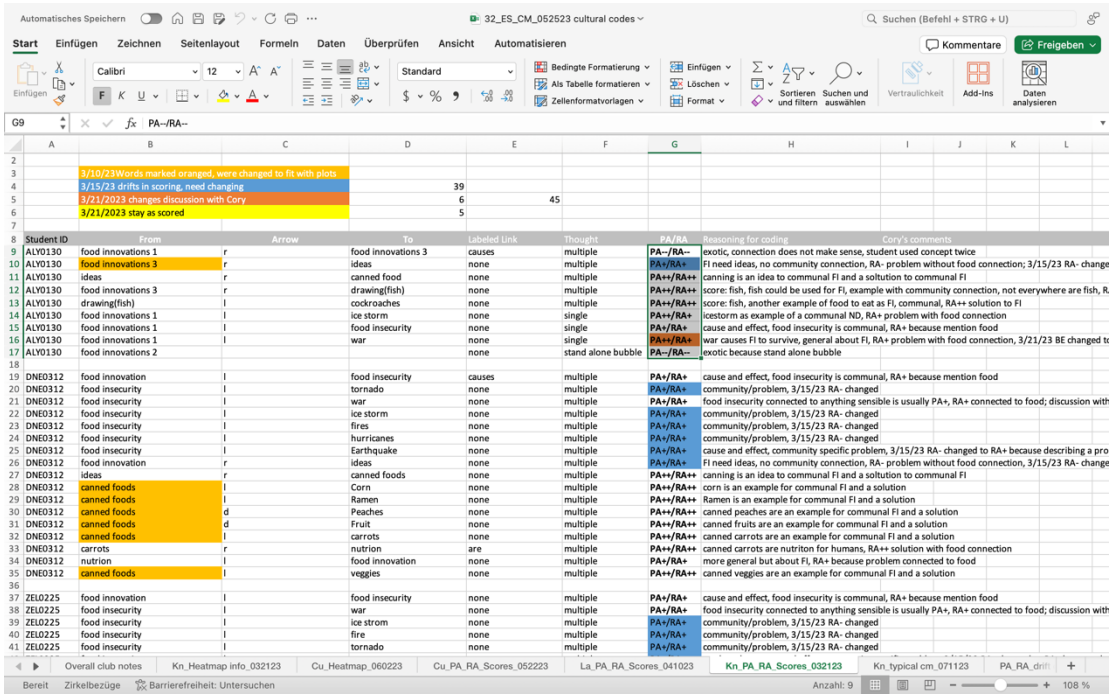
First, I set up the individual student tabs:

Grade	ES					PA/RA ++	2	core	l <- [left, A <- B]		
Gender	Female					PA/RA +	2	ancillary	r -> [right, A -> B]		
Ethnicity	Hispanic or Latino					PA/RA -	-1	asscociated	d <-> [double, A <-> B]		
Race	Hispano o Latino					PA/RA --	-2	unassociated	u - [undirected, A - B]		
Note	11/17/22 N first attempt to caputre concept/links								no arrow between concepts - leave arrow, code arro		
	11/22/22 BE looks over and provides feedback										
	1/4/23 BE PA/RA scoring										
	1/30/31 discussion with CB - canning is general PA++, change line 12										
	2/6/23 changed PA scoring for FI and war										
	3/10/23 changes in yellow - to fit with plot										
	3/15/23 RA- changed to RA+ because describing a problem with food connection										
	First impression horizontal orde subconcepts hae drawings, similar to DNE0312, maybe sat on the same table, original shows colors										
	Language conne Teremoto is spanish for earthquake										
	Culture connect ideas for canned food - connection to home										
							Knowledge				
Number of c	From	arrow	Arrow code	To	labeled link	Score	PA	RA	Thought chain	Reasoning/Notes	
1	food innovation	<-	l	food insecurity	none	PA+/RA+	1	1	multiple		
2	food insecurity	<-	l	war	none	PA+/RA+	1	1	multiple	student added drawing of a tank. 2/6/23 changed PA- to PA+	
3	food insecurity	<-	l	ice strom	none	PA+/RA+	1	1	multiple	student added drawing of snowflake, 3/15/23 RA- changed to RA+ because describing a problem with food connection	
4	food insecurity	<-	l	fire	none	PA+/RA+	1	1	multiple	student added drawing of fire, 3/15/23 RA- changed to RA+ because describing a problem with food connection	
5	food insecurity	<-	l	tornado	none	PA+/RA+	1	1	multiple	student added drawing of tornado, 3/15/23 RA- changed to RA+ because describing a problem with food connection	
6	food insecurity	<-	l	teremoto	none	PA+/RA+	1	1	multiple	student added drawing of teremoto, spanish for earthquake, 3/15/23 RA- changed to RA+ because describing a problem with food connecti	
7	food innovation	->	r	ideas	none	PA+/RA+	1	1	multiple		
8	ideas	<-	l	canned food	none	PA++/RA++	2	2	multiple		
9	canned food	<-	l	fish	none	PA++/RA++	2	2	multiple	student added drawing of a fish	
10	canned food	->	r	corn	none	PA++/RA++	2	2	multiple	student added drawing of a corn	
11	canned food	->	r	fruit	none	PA++/RA++	2	2	multiple	student added drawing of a watermelon piece	
12	canned food	<->	d	food innovation	are	PA++/RA++	2	2	multiple	agreed 11/28/22 double arrow between canned food and food innovation	
13	canned food	<-	l	veggies	none	PA++/RA++	2	2	multiple	student added drawing of veggies, changed to PA++ (agreed with Cory 1/30/23)	

Simultaneously, I added notes that came to mind about the club:

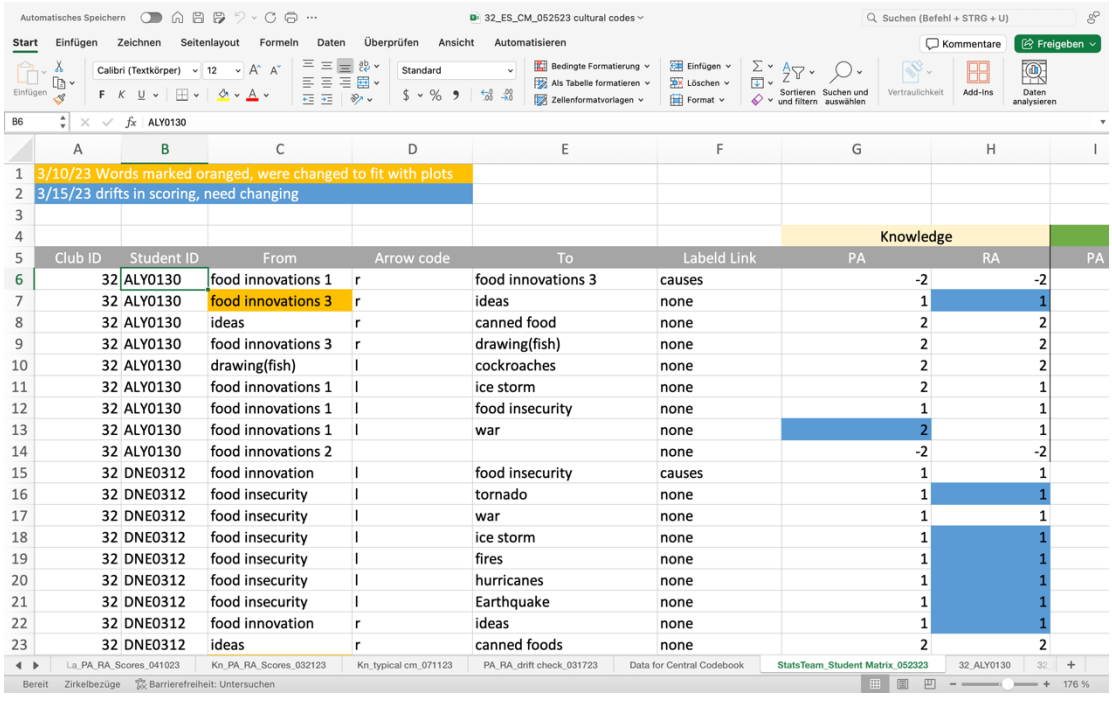


Next, I started scoring:



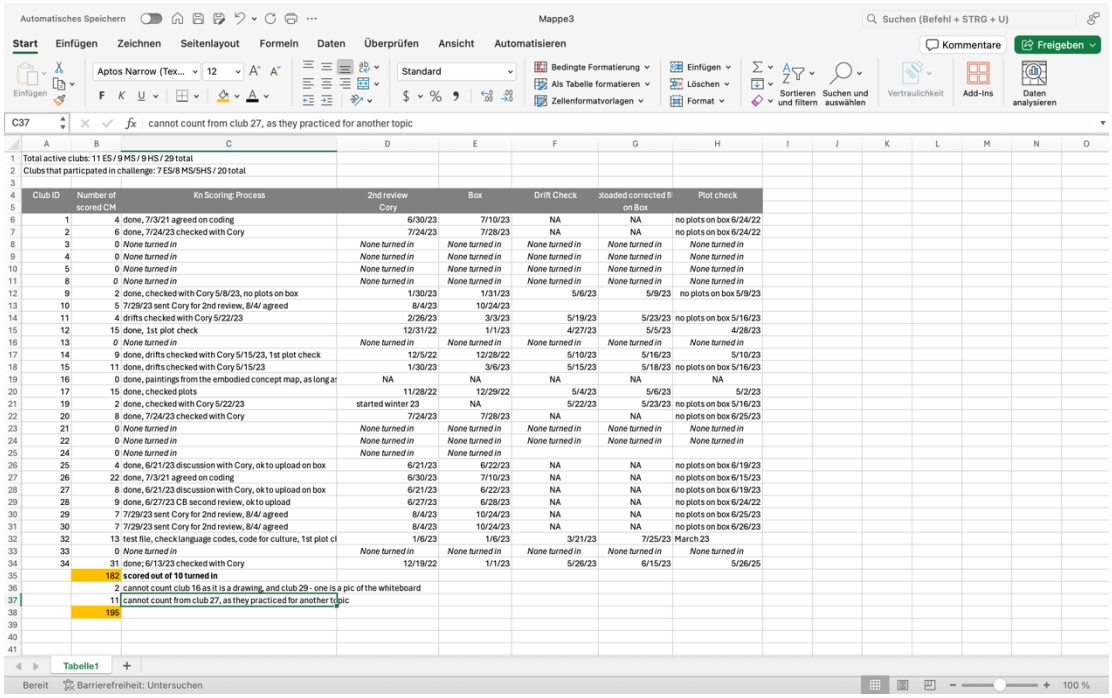
	A	B	C	D	E	F	G	H	I	J	K	L
2												
3		3/10/23Words marked oranged, were changed to fit with plots										
4		3/15/23 drifts in scoring, need changing		39								
5		3/21/2023 changes discussion with Cory		6	45							
6		3/21/2023 stay as scored		5								
7												
8	Student ID	From	Arrow	To	Labeled Link	Thought	PA/RA	Reasoning for coding	Cory's comments			
9	ALY0130	food innovations 1	r	food innovations 3	causes	multiple	PA--/RA--	exotic, connection does not make sense, student used concept twice				
10	ALY0130	food innovations 3	r	ideas	none	multiple	PA+/RA+	FI need ideas, no community connection, RA- problem without food connection; 3/15/23 RA- change				
11	ALY0130	ideas	r	canned food	none	multiple	PA++/RA++	canning is an idea to communal FI and a soltution to communal FI				
12	ALY0130	food innovations 3	r	drawing(fish)	none	multiple	PA++/RA++	score: fish, fish could be used for FI, example with community connection, not everywhere are fish, R				
13	ALY0130	drawing(fish)	l	cockroaches	none	multiple	PA++/RA++	score: fish, another example of food to eat as FI, communal, RA++ solution to FI				
14	ALY0130	food innovations 1	l	ice storm	none	single	PA++/RA+	icestorm as example of a communal ND, RA+ problem with food connection				
15	ALY0130	food innovations 1	l	food insecurity	none	single	PA+/RA+	cause and effect, food insecurity is communal, RA+ because mention food				
16	ALY0130	food innovations 1	l	war	none	single	PA++/RA+	war causes FI to survive, general about FI, RA+ problem with food connection, 3/21/23 BE changed t				
17	ALY0130	food innovations 2			none	stand alone bubble	PA--/RA--	exotic because stand alone bubble				
18												
19	DNE0312	food innovation	l	food insecurity	causes	multiple	PA+/RA+	cause and effect, food insecurity is communal, RA+ because mention food				
20	DNE0312	food insecurity	l	tornado	none	multiple	PA+/RA+	community/problem, 3/15/23 RA- changed				
21	DNE0312	food insecurity	l	war	none	multiple	PA+/RA+	food insecurity connected to anything sensible is usually PA+, RA+ connected to food; discussion with				
22	DNE0312	food insecurity	l	ice storm	none	multiple	PA+/RA+	community/problem, 3/15/23 RA- changed				
23	DNE0312	food insecurity	l	fires	none	multiple	PA+/RA+	community/problem, 3/15/23 RA- changed				
24	DNE0312	food insecurity	l	hurricanes	none	multiple	PA+/RA+	community/problem, 3/15/23 RA- changed				
25	DNE0312	food insecurity	l	Earthquake	none	multiple	PA+/RA+	cause and effect, community specific problem, 3/15/23 RA- changed to RA+ because describing a pro				
26	DNE0312	food innovation	r	ideas	none	multiple	PA+/RA+	FI need ideas, no community connection, RA- problem without food connection, 3/15/23 RA- change				
27	DNE0312	ideas	r	canned foods	none	multiple	PA++/RA++	canning is an idea to communal FI and a soltution to communal FI				
28	DNE0312	canned foods	l	Corn	none	multiple	PA++/RA++	corn is an example for communal FI and a solution				
29	DNE0312	canned foods	l	Ramen	none	multiple	PA++/RA++	Ramen is an example for communal FI and a solution				
30	DNE0312	canned foods	d	Peaches	none	multiple	PA++/RA++	canned peaches are an example for communal FI and a solution				
31	DNE0312	canned foods	d	Fruit	none	multiple	PA++/RA++	canned fruits are an example for communal FI and a solution				
32	DNE0312	canned foods	l	carrots	none	multiple	PA++/RA++	canned carrots are an example for communal FI and a solution				
33	DNE0312	carrots	r	nutrion	are	multiple	PA++/RA++	canned carrots are nutriton for humans, RA++ solution with food connection				
34	DNE0312	nutrion	l	food innovation	none	multiple	PA+/RA+	more general but about FI, RA+ because problem connected to food				
35	DNE0312	canned foods	l	veggies	none	multiple	PA++/RA++	canned veggies are an example for communal FI and a solution				
36												
37	ZEL0225	food innovation	l	food insecurity	none	multiple	PA+/RA+	cause and effect, food insecurity is communal, RA+ because mention food				
38	ZEL0225	food insecurity	l	war	none	multiple	PA+/RA+	food insecurity connected to anything sensible is usually PA+, RA+ connected to food; discussion with				
39	ZEL0225	food insecurity	l	ice strom	none	multiple	PA+/RA+	community/problem, 3/15/23 RA- changed				
40	ZEL0225	food insecurity	l	fire	none	multiple	PA+/RA+	community/problem, 3/15/23 RA- changed				
41	ZEL0225	food insecurity	l	tornado	none	multiple	PA+/RA+	community/problem, 3/15/23 RA- changed				

Finally, I copied necessary information from the students into one matrix to generate heatmaps and student profiles:



	A	B	C	D	E	F	G	H	I
1	3/10/23 Words marked oranged, were changed to fit with plots								
2	3/15/23 drifts in scoring, need changing								
3									
4							Knowledge		
5	Club ID	Student ID	From	Arrow code	To	Labeld Link	PA	RA	PA
6	32	ALY0130	food innovations 1	r	food innovations 3	causes	-2	-2	
7	32	ALY0130	food innovations 3	r	ideas	none	1	1	
8	32	ALY0130	ideas	r	canned food	none	2	2	
9	32	ALY0130	food innovations 3	r	drawing(fish)	none	2	2	
10	32	ALY0130	drawing(fish)	l	cockroaches	none	2	2	
11	32	ALY0130	food innovations 1	l	ice storm	none	2	1	
12	32	ALY0130	food innovations 1	l	food insecurity	none	1	1	
13	32	ALY0130	food innovations 1	l	war	none	2	1	
14	32	ALY0130	food innovations 2			none	-2	-2	
15	32	DNE0312	food innovation	l	food insecurity	causes	1	1	
16	32	DNE0312	food insecurity	l	tornado	none	1	1	
17	32	DNE0312	food insecurity	l	war	none	1	1	
18	32	DNE0312	food insecurity	l	ice storm	none	1	1	
19	32	DNE0312	food insecurity	l	fires	none	1	1	
20	32	DNE0312	food insecurity	l	hurricanes	none	1	1	
21	32	DNE0312	food insecurity	l	Earthquake	none	1	1	
22	32	DNE0312	food innovation	r	ideas	none	1	1	
23	32	DNE0312	ideas	r	canned foods	none	2	2	

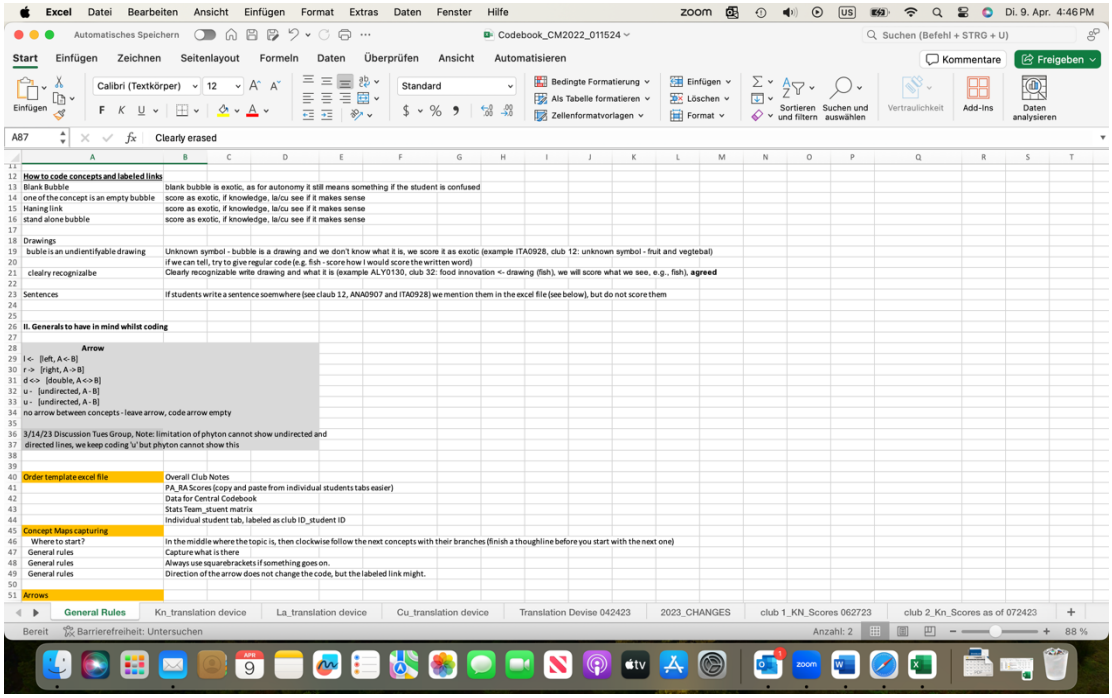
Appendix D: Timeline for Knowledge Scoring



Total active clubs: 11 ES / 9 MS / 9 HS / 29 total
Clubs that particpated in challenge: 7 ES/8 MS/5HS / 20 total

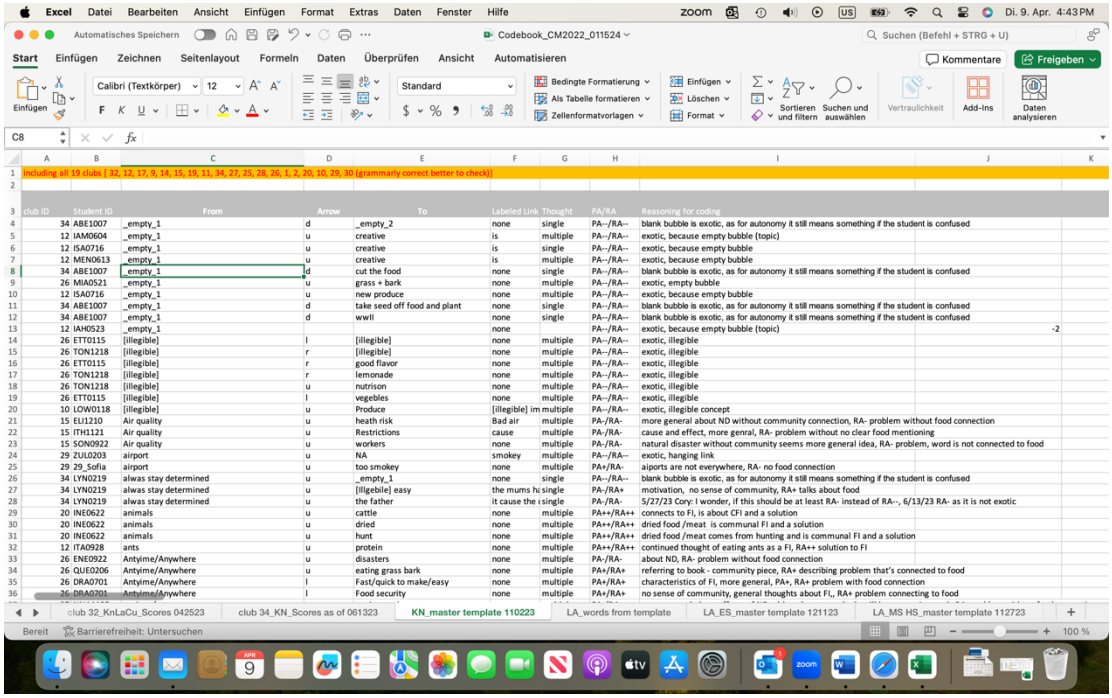
Club ID	Number of scored CM	Kn Scoring Process	2nd review Cory	Box	Drift Check	loaded corrected fi on Box	Plot check
1	4	done, 7/3/21 agreed on coding	6/30/23	7/10/23	NA	NA	no plots on box 6/24/22
2	6	done, 7/24/23 checked with Cory	7/24/23	7/28/23	NA	NA	no plots on box 6/24/22
3	0	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*
4	0	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*
5	0	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*
8	0	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*
9	2	done, checked with Cory 5/8/23, no plots on box	1/30/23	1/31/23	5/6/23	5/9/23	no plots on box 5/9/23
10	5	7/29/23 sent Cory for 2nd review, 8/4/ agreed	8/4/23	10/24/23			
11	4	drifts checked with Cory 5/22/23	2/26/23	3/3/23	5/19/23	5/23/23	no plots on box 5/16/23
12	15	done, 1st plot check	12/31/22	1/1/23	4/27/23	5/5/23	4/28/23
13	0	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*
14	9	done, drifts checked with Cory 5/15/23, 1st plot check	12/5/22	12/28/22	5/10/23	5/16/23	5/10/23
15	11	done, drifts checked with Cory 5/15/23	1/30/23	3/6/23	5/15/23	5/18/23	no plots on box 5/16/23
16	0	done, paintings from the embodied concept map, as long as	NA	NA	NA	NA	NA
17	15	done, checked plots	11/28/22	12/29/22	5/4/23	5/6/23	5/2/23
19	2	done, checked with Cory 5/22/23	started winter 23	NA	5/22/23	5/23/23	no plots on box 5/16/23
20	8	done, 7/24/23 checked with Cory	7/24/23	7/28/23	NA	NA	no plots on box 6/25/23
21	0	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*
22	0	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*
24	0	*None turned in*	*None turned in*	*None turned in*			
25	4	done, 6/21/23 discussion with Cory, ok to upload on box	6/21/23	6/22/23	NA	NA	no plots on box 6/19/23
26	22	done, 7/3/21 agreed on coding	6/30/23	7/10/23	NA	NA	no plots on box 6/15/23
27	8	done, 6/21/23 discussion with Cory, ok to upload on box	6/21/23	6/22/23	NA	NA	no plots on box 6/19/23
28	9	done, 6/27/23 CB second review, ok to upload	6/27/23	6/28/23	NA	NA	no plots on box 6/24/22
29	7	7/29/23 sent Cory for 2nd review, 8/4/ agreed	8/4/23	10/24/23	NA	NA	no plots on box 6/25/23
30	7	7/29/23 sent Cory for 2nd review, 8/4/ agreed	8/4/23	10/24/23	NA	NA	no plots on box 6/26/23
32	13	test file, check language codes, code for culture, 1st plot cl	1/6/23	1/6/23	3/21/23	7/25/23	March 23
33	0	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*	*None turned in*
34	31	done; 6/13/23 checked with Cory	12/19/22	1/1/23	5/26/23	6/15/23	5/26/25
	182	**scored out of 10 turned in**					
	2	cannot count club 16 as it is a drawing, and club 29 - one is a pic of the whiteboard					
	11	cannot count from club 27, as they practiced for another topic					
	195						

Appendix E: Screenshot of Codebook



	A	B
12	**How to code concepts and labeled links**	
13	Blank Bubble	blank bubble is exotic, as for autonomy it still means something if the student is confused
14	one of the concept is an empty bubble	score as exotic, if knowledge, la/cu see if it makes sense
15	Hanging link	score as exotic, if knowledge, la/cu see if it makes sense
16	stand alone bubble	score as exotic, if knowledge, la/cu see if it makes sense
17		
18	Drawings	
19	buble is an undientifyable drawing	Unknown symbol - bubble is a drawing and we don't know what it is, we score it as exotic (example ITA0928, club 12: unknown symbol - fruit and vegtebal)
20		if we can tell, try to give regular code (e.g. fish - score how I would score the written word)
21	clealry recognizalbe	Clearly recognizable write drawing and what it is (example ALY0130, club 32: food innovation <- drawing (fish), we will score what we see, e.g., fish), **agreed**
22		
23	Sentences	If students write a sentence soemwhere (see claub 12, ANA0907 and ITA0928) we mention them in the excel file (see below), but do not score them
24		
25		
26	**II. Generals to have in mind whilst coding**	
27		
28	**Arrow**	
29	l <- [left, A <- B]	
30	r -> [right, A -> B]	
31	d <-> [double, A <-> B]	
32	u - [undirected, A - B]	
33	u - [undirected, A - B]	
34	no arrow between concepts - leave arrow, code arrow empty	
35		
36	3/14/23 Discussion Tues Group, Note: limitation of phyton cannot show undirected and	
37	directed lines, we keep coding 'u' but phyton cannot show this	
38		
39		
40	Order template excel file	Overall Club Notes
41		PA_RA Scores (copy and paste from individual students tabs easier)
42		Data for Central Codebook
43		Stats Team_stuent matrix
44		Individual student tab, labeled as club ID_student ID
45	Concept Maps capturing	
46	Where to start?	In the middle where the topic is, then clockwise follow the next concepts with their branches (finish a thoughline before you start with the next one)
47	General rules	Capture what is there
48	General rules	Always use squarebrackets if something goes on.
49	General rules	Direction of the arrow does not change the code, but the labeled link might.
50		
51	Arrows	

Appendix F: Screenshot of the Knowledge Dictionary



including all 19 clubs [32, 12, 17, 9, 14, 15, 19, 11, 34, 27, 25, 28, 26, 1, 2, 20, 10, 29, 30 (grammarly correct better to check)]

club ID	Student ID	From	Arrow	To	Labeled Link	Thought	PA/RA	Reasoning for coding	
34	ABE1007	_empty_1	d	_empty_2	none	single	PA-/RA--	blank bubble is exotic, as for autonomy it still means something if the student is confused	
12	IAM0604	_empty_1	u	creative	is	multiple	PA-/RA--	exotic, because empty bubble (topic)	
12	ISA0716	_empty_1	u	creative	is	single	PA-/RA--	exotic, because empty bubble	
12	MEN0613	_empty_1	u	creative	is	multiple	PA-/RA--	exotic, because empty bubble	
34	ABE1007	_empty_1	d	cut the food	none	single	PA-/RA--	blank bubble is exotic, as for autonomy it still means something if the student is confused	
26	MIA0521	_empty_1	u	grass + bark	none	multiple	PA-/RA--	exotic, empty bubble	
12	ISA0716	_empty_1	u	new produce	none	multiple	PA-/RA--	exotic, because empty bubble	
34	ABE1007	_empty_1	d	take seed off food and plant	none	single	PA-/RA--	blank bubble is exotic, as for autonomy it still means something if the student is confused	
34	ABE1007	_empty_1	d	wwll	none	single	PA-/RA--	blank bubble is exotic, as for autonomy it still means something if the student is confused	
12	IAH0523	_empty_1			none		PA-/RA--	exotic, because empty bubble (topic)	-2
26	ETT0115	[illegible]	l	[illegible]	none	multiple	PA-/RA--	exotic, illegible	
26	TON1218	[illegible]	r	[illegible]	none	multiple	PA-/RA--	exotic, illegible	
26	ETT0115	[illegible]	r	good flavor	none	multiple	PA-/RA--	exotic, illegible	
26	TON1218	[illegible]	r	lemonade	none	multiple	PA-/RA--	exotic, illegible	
26	TON1218	[illegible]	u	nutrison	none	multiple	PA-/RA--	exotic, illegible	
26	ETT0115	[illegible]	l	vegebles	none	multiple	PA-/RA--	exotic, illegible	
10	LOW0118	[illegible]	u	Produce	[illegible] im	multiple	PA-/RA--	exotic, illegible concept	
15	ELI1210	Air quality	u	heath risk	Bad air	multiple	PA-/RA-	more general about ND without community connection, RA- problem without food connection	
15	ITH1121	Air quality	u	Restrictions	cause	multiple	PA-/RA-	cause and effect, more genral, RA- problem without no clear food mentioning	
15	SON0922	Air quality	u	workers	none	multiple	PA-/RA-	natural disaster without community seems more general idea, RA- problem, word is not connected to food	
29	ZUL0203	airport	u	NA	smokey	multiple	PA-/RA--	exotic, hanging link	
29	29_Sofia	airport	u	too smokey	none	multiple	PA+/RA-	aiports are not everywhere, RA- no food connection	
34	LYN0219	alwas stay determined	u	_empty_1	none	single	PA-/RA--	blank bubble is exotic, as for autonomy it still means something if the student is confused	
34	LYN0219	alwas stay determined	u	[illgeible] easy	the mums h	single	PA-/RA+	motivation, no sense of community, RA+ talks about food	
34	LYN0219	alwas stay determined	u	the father	it cause the	single	PA-/RA-	5/27/23 Cory: I wonder, if this should be at least RA- instead of RA--, 6/13/23 RA- as it is not exotic	
20	INE0622	animals	u	cattle	none	multiple	PA++/RA++	connects to FI, is about CFI and a solution	
20	INE0622	animals	u	dried	none	multiple	PA++/RA++	dried food /meat is communal FI and a solution	
20	INE0622	animals	u	hunt	none	multiple	PA++/RA++	dried food /meat comes from hunting and is communal FI and a solution	
12	ITA0928	ants	u	protein	none	multiple	PA++/RA++	continued thought of eating ants as a FI, RA++ solution to FI	
26	ENE0922	Antyime/Anywhere	u	disasters	none	multiple	PA-/RA-	about ND, RA- problem without food connection	
26	QUE0206	Antyime/Anywhere	u	eating grass bark	none	multiple	PA+/RA+	referring to book - community piece, RA+ describing problem that's connected to food	
26	DRA0701	Antyime/Anywhere	l	Fast/quick to make/easy	none	multiple	PA+/RA+	characteristics of FI, more general, PA+, RA+ problem with food connection	
26	DRA0701	Antyime/Anywhere	l	Food security	none	multiple	PA+/RA+	no sense of community, general thoughts about FI,, RA+ problem connecting to food	

Appendix G: Poem

Title: Analyzing Concept Maps with LCT

By Barbara, Cory, Jessica, Madi

On Monday 15th of May 2023, we wrote this poem to explain our research process:

To see what a student knows of a topic,
Give them some paper and a concept.
Pick some theme like food innovation,
And then you can learn from their creation.

Setting things up wasn't easy – we yelped,
But with time, Excel and a team that helped.
We came up with a translation device,
As this could help us to be precise.

Using LCT the maps are scored,
PA for ideas, RA for purpose to explore.
Canned food, Ramen, Tornados, and war,
Giving pluses or minuses sometimes we aren't sure.

From food innovation to concepts to heatmaps,
Positions, relations, autonomy tours.
With healthy candy canes to feed hungry people,
SMILE club students making food more secure.

Appendix H: Student Profiles Rules

Rule 1. XX-only (e.g., sovereign-only, or introjected-only)

a) If 100% of the scores are in the sovereign quadrant (PA+, RA+) we will call it "sovereign only knowledge", or "sovereign only language" or "sovereign only culture" depending on the strand.

b) If 100% of the scores are in the projected quadrant (PA+, RA-) we will call it "projected only knowledge", or "projected only language", or "projected only culture" depending on the strand.

c) If 100% of the scores are in the introjected quadrant (PA-, RA+) we will call it "introjected only knowledge", or "introjected only language" or "introjected only culture" depending on the strand.

d) If 100% of the scores are in the exotic quadrant (PA-, RA-) we will call it "exotic only knowledge", or "exotic only language", or "exotic only culture" depending on the strand.

Rule 2. Mix
If there is at least one score in each of the 4 quadrants, we will call it "mixed-knowledge", or "mixed-language" or "mixed-culture" depending on the strand. Note that rule 2 and rule 3 can both apply. When that happens, rule 3 takes precedence and we name it for the dominant quadrant.

Rule 3. XX-Dominant (e.g., sovereign-dominant, or introjected-dominant)
If 50% or greater of the scores are in one quadrant, we will name it based on that quadrant, e.g., "sovereign-dominant knowledge", or "projected-dominant language", or "exotic-dominant culture" depending on the quadrant and strand.

Rule 4. XX-Left Out
If one quadrant is empty, we call it left out. For example, in the cultural heatmap there are no scores in the projected quadrant (PA+, RA-), we will call it "projected-left out culture". Note that rule 3 and rule 4 can both apply. When that happens, rule 3 takes precedence and we name it for the dominant quadrant.

Rule 5. 50:50
If there is the same number of scores in two quadrants (tie), we call it 50:50. For example, in the knowledge heatmap there is 1 score in the exotic (PA-, RA-) and 1 score in the introjected quadrant (PA-, RA+), we will call it "50:50".

Appendix I: How to Read Student Profiles

Knowledge	Rule	Possible Distribution within Quadrants
50:50 Exotic-Sovereign	50% of the concepts are either in the exotic (PA-, RA-) or sovereign (PA+, RA+) quadrant.	*Associated PA-, RA-:* Associated concepts were somehow related to the topic (PA-) to describe a problem that was unrelated to food (RA-). *Unassociated PA--, RA—* Hanging links, empty bubbles.
Exotic dominant	50% or more of the concepts are in the exotic quadrant (PA-, RA-).	*Ancillary PA+, RA+ or associated PA-, RA-:* Concepts were somehow related to food and the topic (PA-) and talked about a problem that is not related to food (RA-). Whereas the other 50% are sovereign (ancillary, PA+/RA+) meaning that concepts are either about FI or have a community connection (PA+) and are clearly describing something about food (RA+).
Introjected left out	No scores in the introjected quadrant (PA-, RA+), meaning that concepts where somehow related to the topic and food	It was not necessary for the students use concepts that were somehow related to the topic and food (PA-), and either describing something about food (RA+) or proposing a solution to food insecurity (RA++).
Introjected-dominant	50% or more of the scores are in the introjected quadrant (PA-/RA+), meaning concepts pursue a different topic.	PA-, RA+ Different topic (PA-) means that concepts are neither about community nor FI, yet they are related about food and somehow related to the topic.
Mix	There are scores in each quadrant.	
Projected-dominant	50% or more of the scores are in the projected quadrant (PA+, RA-).	Even if concepts are on topic, they pursue the purpose to talk about a problem that is

		unrelated to food, no attempt for a solution (RA-).
Sovereign-only	100% of the scores are in the sovereign quadrant (PA+, RA+), because concepts are about CFI (on topic, PA+) and mean to improve or solve food insecurity through FI (on purpose, RA+)	*Ancillary (PA+, RA+):* Concepts are either about FI or have a community connection (PA+) and are clearly describing something about food (RA+). *Core (PA++, RA++):* Concepts are about CFI (PA++) and mention FI as a solution to food insecurity (RA++). *Core/ancillary (PA++, RA+):* Concepts are about CFI (PA++) and are clearly describing something about food (RA+)
Sovereign-dominant	50% or more of the scores are in the sovereign quadrant (PA+/RA+). Concepts are on topic (PA+) and on purpose (RA+).	*Sovereign Core (PA++, RA++):* Concepts are about CFI (PA++) and mention FI as a solution to food insecurity (RA++). *Sovereign Ancillary (PA+, RA+):* Concepts are either about FI or have a community connection (PA+) and are clearly describing something about food (RA+). *Sovereign Core/Ancillary (PA++/RA+):* Concepts are about CFI that describe something about food (RA+). *Projected (different purpose PA+, RA-):* Different purpose means talking about a problem without food connection. *Introjected (different topic PA-, RA+):*

		Different topic means talking more general about ND, such as talking about food insecurity and not CFI.

Language	Rule	Possible Distribution within Quadrants
Exotic dominant	50% or more of the concepts are in the exotic quadrant (PA-, RA-).	Associated (PA-, RA-) or Unassociated (PA-, RA--): Used concepts are from the template provided (PA-) to describe something (RA-), such as 'ND [causes] food insecurity' or are exotic, such as empty bubbles (RA--).
50:50 Exotic-projected	50% of the concepts are in the projected quadrant (PA+, RA-) whereas the other 50% are in the exotic quadrant (PA-, RA-).	*Exotic (PA-, RA-) and P (PA+, RA-):* Student uses a mix from other words and words from the template (PA+) to just describe something (RA-). Whereas the other 50% are exotic (PA-/RA-) meaning that concepts are words from the template (PA-) to just describe (RA-).
Introjected-only	There are only scores in the introjected quadrant (PA-, RA+)	Off topic means that the student used words from the template (PA-) to talk about practical real-life solution (RA++) or encourage that something needs to be done (RA+).
Introjected-left out	There are no scores in the introjected quadrant (PA-/RA+).	In other words, these students did not use words from us (PA-) to communicate their ideas.
Mix	There are scores in each quadrant.	*Sovereign quadrant (PA+, RA+):* On topic and on purpose. *Projected quadrant (PA+, RA-):* Words not from template or mix (PA+). Different purpose (RA-) means for example just describing or couldn't finish proposition

		Exotic quadrant (PA-, RA-): Off topic means that the student used words from the template (PA-) to just describe something (RA-). *Introjected quadrant (PA-/RA+):* Off topic means that the student used words from the template (PA-) to encourage that something needs to be done (RA+) or describe a real-life situation (RA++).
Projected-left out	There are no scores in the projected quadrant (PA+, RA-).	In other words, students did not just describe something (RA-) to communicate about the topic (PA+).
Projected dominant	50% or more of the concepts are in the projected quadrant (PA+, RA-), meaning that the purpose was to describe something instead of solving a problem (RA-).	*PA++, PA+, RA- or RA—* Students used either other words (PA++), such as healthy environment or produce, or a mix of other words and some from the template (PA+), such as 'forest fires [could harm] livestock' with the purpose to either describe (RA-), such as 'livestock [could harm] produce' or wrote word that were illegible (RA--). *PA+ or PA++, RA-:* 50% or more of the concepts are in the projected quadrant (PA+, RA-), meaning that the purpose was to describe something instead of solving a problem (RA-). Concepts are either from the students (PA++) or a mix of other words and words from the template (PA+).
50:50 Projected-sovereign	50% of the concepts are in the projected quadrant (PA+, RA-) whereas the other 50% are in the sovereign quadrant (PA+, RA+).	*Projected (PA+, RA-) and Sovereign (PA+, RA+ or RA++):* Concepts are projected (PA+/RA-), meaning the students use a mix of other words and words from the template (PA+) to just describe something (RA-). Whereas the

		other 50% of the concepts are sovereign (PA+, RA+ or RA++) meaning students use a mix of other words and words from the template (PA+) to either vaguely talk about that something needs to be done (RA+) or propose a practical real-life solution (RA++).
Sovereign-left out	There are no scores in the sovereign quadrant (PA+, RA+)	It wasn't necessary for the student to use non pregiven words (PA++) and/or a mix from words from the template and own (PA+) to talk about a practical real-life solution (RA++) or encourage that something needs to be done (RA+).
Sovereign-dominant	50% or more of the scores are in the sovereign quadrant (PA+/RA+).	*Cory/core (PA++, RA++):* Student used other than pre-given words (PA++) to talk about a real-life solution (RA++). *Ancillary/core (PA+, RA++):* Student uses a mix of other words and words from the template (PA+) to talk about a real-life solution (RA++). *Ancillary/ancillary (PA+/RA+):* Student uses a mix of other words and words from the template (PA+) to address vaguely that something needs to be done (RA+). *Core/ancillary PA++, RA+* Student uses other words (PA++) to address vaguely that something needs to be done (RA+).

Culture	Rule	Possible distribution with quadrants
Exotic-dominant	50% or more of the scores are in the exotic quadrant (PA-/RA-). In other words, concepts are learned (PA-) and either unrelated to problem solving (RA-) or illegible (RA--).	*PA-, RA or PA--, RA--:* The majority of propositions are learned (PA-), such as healthy environment or ND, and unrelated to problem solving, more describing (RA-), such as ND - livestock. Two propositions are illegible (PA--, RA--). *PA-, RA-:* 50% or more of the scores are in the exotic quadrant (PA-, RA-). In other words, concepts are learned (PA-) and unrelated to problem solving (RA-).
Exotic left out	There are no scores in the exotic quadrant (PA-, RA-).	Students did not use words from the template only (PA-) to just describe something that is unrelated to problem solving (RA-).
50:50 Exotic-Introjected	50% of the concepts are in the introjected quadrant (PA-, RA+) whereas the other 50% are in the exotic quadrant (PA-, RA-).	*Exotic (PA-, RA-) and Introjected (PA-, RA+)* Concepts are introjected (PA-, RA+), meaning students used learned concepts (PA-) to talk more generally about problem solving (RA+). Whereas the other 50% of the concepts are exotic (PA-, RA-) meaning students used learned concepts (PA-) to describe something that is unrelated to problem solving (RA-).
Introjected dominant	50% or more of the concepts are in the introjected quadrant (PA-, RA+).	Different topic (PA-) means that students used learned concepts to either talk more generally about problem solving (RA+) or propose a feasible and culturally connected solution (RA++).

Introjected only	All concepts are in the introjected quadrant (PA-, RA+).	Different topic (PA-) means that students used learned concepts.
Mixed	There are scores in each quadrant.	Students used experienced (PA+) and learned concepts (PA-) to either propose a feasible culturally connected solution (RA++), propose a general solution to the problem (RA+) or used something unrelated to problem solving.
Projected dominant	50% or more of the scores are in the projected quadrant (PA+, RA-).	*PA+, RA-:* Students use experienced concepts without CFI (PA+) to just describe something that is unrelated to problem solving (RA-).
Projected-left out	There are no scores in the projected quadrant (PA+/RA-). In other words, students did not use experienced concepts (PA+) to describe a problem (RA-).	*Sovereign (PA+/RA+):* Students used familiar concepts that are connected to the topic of FI (PA++) or are not connected to FI (PA+), which are feasible and communal solutions (RA++), described the relation between something experienced in their community, such as ice storm or fire, or used more general ideas to solve a given problem (RA+). *Introjected (PA-/RA+):* Different topic means the use of learned concepts (PA-), such as food insecurity or war. Exotic (PA-/RA-): Different topic means the us of learned concepts (PA-) that are unrelated to problem solving (RA-), or are stand-alone bubbles, hanging links (PA--/RA--). Stand-alone bubbles and hanging links (PA--/RA--) demonstrate that students either had not enough practice or could not finish their maps on time.

Sovereign-dominant	50% or more of the scores are in the sovereign quadrant (PA+/RA+). In other words, student used concepts, they are familiar with, such as examples for canned food, pie or candy (PA+) to say something about problem solving (RA+).	*Sovereign (PA+/RA+):* Students mention concepts they are familiar with, and which are FI (PA++), such as ramen, chips, to propose a feasible and culturally connected solution (RA++). They also mention familiar concepts (PA+), such as Ramen as FI, but might not see the cultural connection and/or talk more general about problem solving (RA+). *Ancillary, PA+, RA+:* Propositions are experienced without CFI (PA+) but are generally about problem solving (RA+), such as 'ND and dangerous air quality' or 'forest fires and bad stuff in air'.
Sovereign-only	100% of the scores are in the sovereign quadrant (PA+/RA+).	
Sovereign left out	No scores in the sovereign quadrant (PA+, RA+).	In other words students used just learned concepts (PA-) to describe something unrelated to problem solving (RA-).
Sovereign left out	There are no scores in the sovereign quadrant (PA+, RA+).	In other words, there are no experienced concepts with or without FI connection (PA++, PA+) that solve a problem (RA++, RA+).

Appendix J: Interview Guide

A. Start by reading introductions to the interviewee:
Hello, thank you for taking the time to talk with me today. I am interested to hear your experiences about the concept map activity during the challenge and your general understanding about concept maps as a tool for science meaning making.
Participation is purely voluntary, and you can stop participating at any time. Participating or not participating poses no risks to you personally or professionally. However, it may help improve support for future teachers, so I hope that you will participate. *Do you agree to participate?*
Everything you say here is confidential. I will never attach your name or any other identifying information to what you say here. I will be sharing some of the themes of our conversation with the LaCuKnoS research team. I may also use themes from this interview as part of the writing I am doing. The purpose of this research is to help improve LaCuKnoS tools and practices for you and future participants, as well as to understand more about how teachers use concept maps in their classrooms. *Is it okay that I record this conversation?*
If you have questions or concerns regarding this interview, you can always contact Cory Buxton or myself *[put phone and e-mail in the chat if on zoom]*. Do you have any questions for me before we begin?

B. Questions

I. General questions about the club and concept maps

1. Tell me more about your club this year.
2. Besides the challenge. Do you have any other experiences with concept maps?

II. Mapping activity during the challenge

3. [Pre-Question PA] I know it was a while ago but what was the main content or big ideas you wanted your students to learn during the challenge?
4. [Pre-Question RA] Why do you think it is valuable for your students to learn this main content or big idea?
5. How did you facilitate the concept map activity during the challenge?

Let me show you some of the concept maps your students constructed. [give some time to look at those]

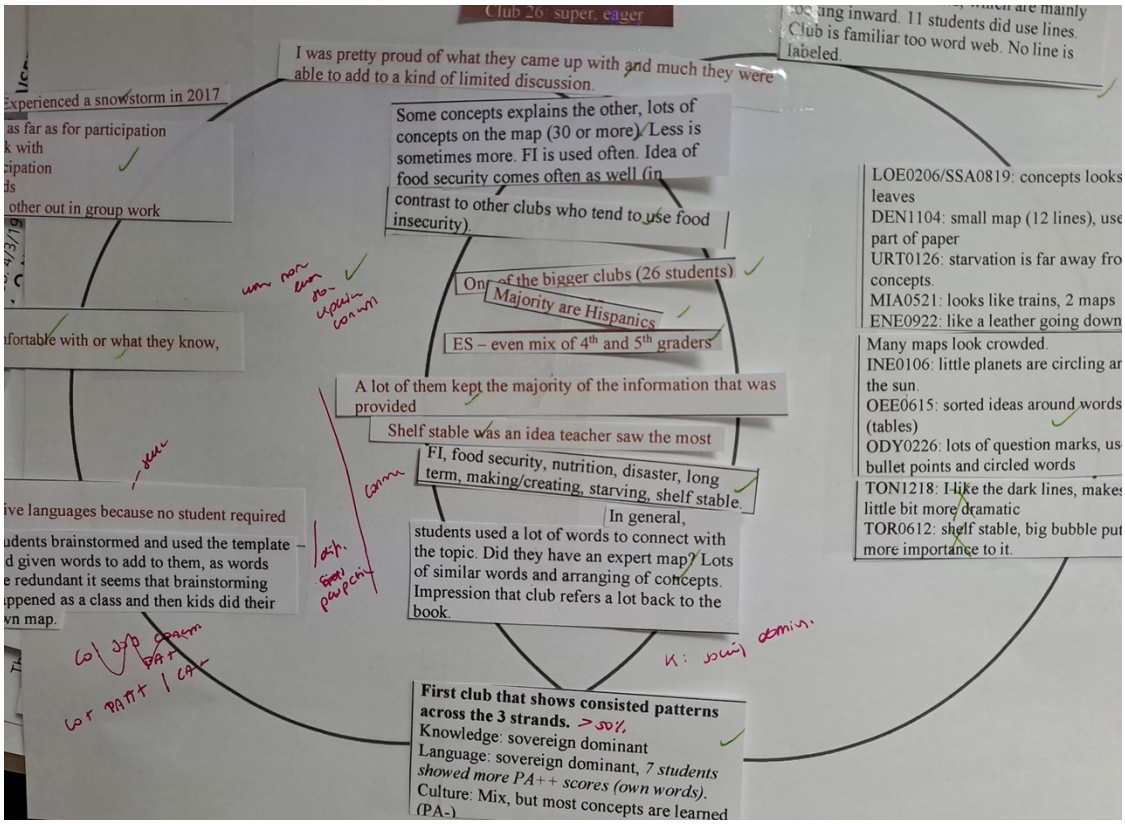
6. [Question about PA] How do you see these concept maps reflecting the main content or big ideas from the challenge?
7. [Question about RA] How do you see these concept maps reflecting students' reasons or purposes for knowing these big ideas?
8. How did your students respond to the concept map activity?
9. [LaCuKnoS related] Do you think concept maps give your students an opportunity to make language choices that can help them make meaning of science in their lives? If so, how?
10. [LaCuKnoS related] Do you think concept maps give your students an opportunity to make connections to cultural or community knowledge that can help them make meaning of science in their lives? If so, how?

III. Closure

11. As we were talking, is there anything that comes to your mind I didn't ask.

C. Read wrap up to interviewee:
These were my questions for today. Thank you for taking the time to meet with me today. I appreciated learning about your experience. Do you have any questions for me before we finish? Thank you again!

Appendix K: Venn Diagram



Appendix L: Detailed Information Student Profiles at the Club Level

Club ID	Knowledge	Language	Culture
Club 1 (MS) 5 Students Trend	1 Mix 1 Introjected left out 1 Sovereign dominant 1 50:50 exotic-sovereign 1 Exotic dominant Heterogeenous	2 Projected dominant 2 Exotic dominant 1 50:50 exotic-projected Exotic – projected range	2 Exotic dominant 2 Sovereign dominant 1 Exotic only Exotic AND Sovereign
Club 2 (HS) 4 Students Trend	2 Mix 1 Sovereign dominant 1 Projected dominant Heterogeneous	2 Projected left out 1 Mix 1 Sovereign dominant Heterogeneous	2 Mix 1 Exotic left out 1 Sovereign dominant Heterogeneous
Club 3 (MS) 2 CONCEPT MAPS / 7 students Trend	2 Introjected dominant Introjected trend	50% 50:50 P and S 50% Projected dominant More projected scores	50% 50:50 E and I 50% Exotic Dominant More exotic scores
Club 4 (ES) 15 Students	6 Sovereign only knowledge / Sovereign only language /Introjected only culture 3 Sovereign only knowledge / Sovereign dominant language / Introjected dominant culture 5 Sovereign dominant knowledge / Sovereign dominant language / Introjected dominant culture 1 Outlier: Sovereign dominant knowledge / Sovereign dominant language / Introjected only culture		
Club 5 (HS) 9 Students Trend	4 Mix 2 Sovereign dominant 2 Introjected left out 1 Exotic dominant Heterogeneous	4 Sovereign dominant 4 Mix 1 Exotic dominant Heterogeneous	5 Mix 2 Introjected dominant 1 Projected dominant 1 Sovereign dominant Heterogeneous
Club 6 (MS) 9 Students Trend	5 Projected dominant 3 Introjected left out 1 Sovereign dominant Heterogeneous	4 Projected dominant 2 Mix 2 Sovereign dominant 1 Introjected left out Heterogeneous	5 Exotic dominant 2 Mix 1 Sovereign left out 1 Introjected dominant Heterogeneous
Club 7 (ES) 22 Students	8 Sovereign dominant knowledge / Sovereign dominant language /Mix culture 2 Sovereign dominant knowledge / Sovereign dominant language / Projected left out culture 2 Sovereign dominant knowledge / Sovereign dominant language / Introjected dominant culture 4 Sovereign dominant knowledge / Mix language / Mix culture 6 Outlier: 1 Sovereign only knowledge / Sovereign dominant language / Introjected dominant culture 1 Sovereign only knowledge / Sovereign dominant language / Mix culture		

	1 Sovereign dominant knowledge / Introjected left out language / Sovereign left out culture 1 Sovereign dominant knowledge / Sovereign only language / Introjected dominant culture 1 Sovereign dominant knowledge / Mix language / Introjected dominant 1 Mix knowledge / Introjected left out language / Exotic dominant culture		
Club 8 (MS) 7 Students	5 Projected dominant knowledge / Sovereign dominant language /Mix culture 2 Outlier: 1 Introjected left out knowledge / Sovereign dominant language / Mix culture 1 Exotic dominant knowledge / Sovereign dominant language / Mix culture		
Curious Minds (ES) 13 students	8 S-dominant 5 S- only	6 Mixed 2 Sovereign-dominant 1 Sovereign left out 1 Introjected only 2 Introjected left out 1 Introjected dominant	8 Sovereign-dominant 1 Sovereign only 1 Mixed 3 Projected Left out
Trend	Sovereign trend	Heterogeneous	9/13 sovereign trend