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Exploring the 'Black Box' of Science, Technology, Engineering, and Mathematics Learning

An Epistemic Network Analysis of Three STEM Activities

Dagmar Hedman

Doctoral Thesis in Education at Stockholm University, Sweden 2025

Exploring the 'Black Box' of Science, Technology, Engineering, and Mathematics Learning

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Academic dissertation for the Degree of Doctor of Philosophy in Education at Stockholm University to be publicly defended on Monday 9 June 2025 at 13.00 in auditorium 2403, Frescativägen 54.

Abstract

The effectiveness of STEM activities for teaching subject knowledge and 21st century skills is often lauded in educational research. In order to critically assess these claims, this research explores beyond the pedagogical approaches used to design or assess a STEM activity, and instead tries to understand the learning processes that take place over the course of an activity itself. This change in perspective enhances a simplistic input-output model of learning, and allows for an exploration of the learning opportunities that develop within a non-formal STEM activity context as a result of the interactions taking place among the participants. These opportunities for learning can provide additional explanatory power to understanding why STEM activities are considered effective for learning. This research also looks into two specific design elements of non-formal STEM activities: the use of engineering students as mentors; and the hands-on building, i.e., ‘making’ of a STEM artefact.

This research project employed a quantitative ethnographic (QE) approach to attribute meaningful insights into learning processes associated with the verbal and non-verbal interactions that took place between groups of STEM activity participants and their learning environments. This research collected audiovisual data of three groups taking part in three different non-formal STEM activities. This data was coded to isolate epistemic codes for STEM subject knowledge (science, technology, engineering, and mathematics) and four 21st century skills (communication, collaboration, creativity, and critical thinking). This data was then formatted for applying an epistemic network analysis (ENA). The resulting ENA network models mapped how all eight of these epistemics cooccurred within the verbal and non-verbal interactions of the participants. The ENA models were investigated to accomplish two tasks. The first task was to identify significant patterns of cooccurrence to identify how knowledge and skills were associated within the STEM activities. The second task was to return to the source data that underpinned these significant moments in order to be better understand these patterns based on the 'culture' that the participants generated within their contexts. By returning to the source data, this research attempted to 'close the analytical loop' between what the findings of the ENA displayed, and how meaningful insights into understanding these patterns in terms of opportunities for learning are contextualized within the three non-formal STEM activities, and within each group of participants.

The findings of this research project revealed that knowledge and skills epistemics manifested different network models for each case, and with statistically significant differences in the patterns of cooccurrence amongst the participants based on the roles that they undertook within the activity. Also, this research uncovered that the use of expert mentors increased instances of STEM knowledge epistemics being displayed within the learning environments, however, these mentors did not show significant differences in their practice of 21st century skills when compared to the other participants. Finally, it was found that the hands-on activity of 'making', and more specifically 'tinkering', produced the strongest connections between and among STEM knowledge and 21st century skills epistemics across most of the participants within all of the activities.

The results of this research project cast a light into the ‘black box’ of STEM learning and illuminated some possible explanations for how the activity participants are presented with, and develop, opportunities to learn STEM subject knowledge or practice 21st century skills. The use of ENA aided in highlighting these opportunities by revealing the complex patterns of cooccurrence between these two aspects of STEM learning. At the conclusion of this research project, it is possible to provide more meaningly explanations as to why the STEM activities examined here can be effective for learning.

Keywords: *STEM, STEM activities, 21st century skills, quantitative ethnography, epistemic network analysis, non-formal learning, making, mentoring.*

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Exploring the ‘Black Box’ of Science, Technology, Engineering, and Mathematics Learning:

An Epistemic Network Analysis of Three STEM Activities

Dagmar Hedman

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List of Abbreviations

4C’s	Four C’s of 21st Century Learning
AI	Artificial Intelligence
BBC	British Broadcasting Corporation
CI	Confidence Interval
CMC	Computer Mediated Communication
CoP	Community of Practice
COVID-19	Corona Virus Disease-2019
DBER	Discipline-Based Education Research
ENA	Epistemic Network Analysis
F2F	Face-to-Face
GDPR	General Data Protection Regulation
IBL	Inquiry-Based Learning
ICT	Information and Communication Technology
IR	Infrared
LA	Learning Analytics
MMLA	Multimodal Learning Analytics
MMR	Mixed Methods Research
MOOC	Massive Open Online Course

NSF	National Science Foundation
OBL	Object-Based Learning
OECD	Organization for Economic Co-Operations and Development
OMC	Object-Mediated Communication
OML	Object-Mediated Learning
P21	Partnership for 21st Century Skills
PBL	Problem-Based Learning
PjBL	Project-Based Learning
PLE	Programming Language Environment
QDA	Qualitative Document Analysis
QE	Quantitative Ethnography
RPP	Research-Practice Partnerships
SDP	School Development Program
SNAE	Swedish National Agency for Education (Swedish: *Statens Skolverket*)
STEAM	Science, Technology, Engineering, Arts, and Mathematics
STEM	Science, Technology, Engineering, and Mathematics
SVD	Singular Value Decomposition
TCS	21st Century Skills *(abbreviated coded epistemic)*
TLM	Teaching and Learning Materials
TTCT	Torrance Tests of Creative Thinking
VPL	Visual Programming Language

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Preface: Dissertation Summary

This PhD dissertation is presented within the typical parameters of how research documents are generally organized. Following an introduction to what this research project aims to understand, there is a brief overview of the contextual and thematic concepts that are involved in laying the foundations for the investigation. Prior to presenting the findings, a section discussing the methodology goes into detail about specific aspects of how this project was conducted, and how the use of relatively new analytical tools aided in this investigation. Finally, the results are discussed in relation to poignant details derived from the analysis in an effort to provide very general, and practical, implications for how this project can inform educational practice in relatable learning scenarios.

This research project is interested in understanding the goings-on within specific learning activities. These specific learning activities are framed within the integrated subject of STEM, which stands for Science, Technology, Engineering, and Mathematics. From both a teaching and a learning perspective, STEM education approaches these four subjects as entwined rather than as separate disciplines that should be taught in separate classrooms by separate teachers. This integrated approach to blending these four subjects into one, i.e., STEM, requires that knowledge in all four of these subjects be acquired or utilized in order to solve a problem, or accomplish a given task. These problems or tasks are typically reflective of issues and challenges learners will face outside of a classroom setting where there is no clear distinction between the four subjects. The learning and teaching of STEM takes on the perspective that real-world problems and issues require integrating knowledge from all of these subjects, and so the teaching and learning of STEM should reflect this reality.

When looking at the goings-on within a STEM activity, this research takes on an approach that focuses less on a systems theory of identifying inputs into a STEM learning context, and later evaluating an output to determine the success, value, or effectiveness of the activity (Bhaskar & Lajwanti, 2019). Rather, the goings-on are identified as the interconnected processes that take place within the activity, and which can give meaning to how learning takes place within a STEM activity based on what opportunities for learning can be identified when framing STEM activities within various pedagogies.

STEM education can take many pedagogical forms. One of the ways that STEM is implemented, either in the classroom or within non-formal educational settings, is with a STEM activity. STEM activities are often designed to promote hands-on, collaborative, problem-based learning that are intended to support the development of knowledge and to encourage the use of modern workplace competencies such as 21st century skills. These pedagogical strategies are applied in order to accomplish three main goals, and it is the assessment of these outcomes that determine the effectiveness of a STEM activity. Effective STEM activities are those that promote an interest in STEM career trajectories and improve subject knowledge when compared to more traditional teaching contexts. Furthermore, involvement in STEM activities is suggested to help in the development of social and workplace skills needed for global competitiveness in STEM fields (Devrani et al., 2024).

However, as stated earlier this research does not focus on looking at the outputs of STEM activities, but rather on the processes (e.g., interactions and conversations) that take place over the course of the activity itself. This focus also does not assign causal understanding of all of the inputs into the STEM activity system, but rather how these various inputs are interacting and related in a manner that can help shed light on processes related to these inputs.

This research focuses on four specific 21st century skills. These four skills are collaboration, communication, creativity, and critical thinking (i.e., the 4C's). These four specific skills are not the only soft skills involved in STEM learning but they are prominent within the STEM literature. However, it is not often that all four of these skills are examined together with respect to how they cooccur with each other, and how they cooccur with the four STEM subject-based knowledge constructs. This complex web of interaction and cooccurrence among all of these elements hopes to capture more of the complexity of knowledge and skills utilization and development over the course of STEM activity participation.

Although academic literature promotes the idea that STEM education positively influences knowledge and skills development outcomes, there is not as much published work that details what takes place during the course of a STEM activity, and how this information might contribute to understanding STEM learning in relation to these outcomes. Furthermore, this project employs a methodology that investigates all of the identified variables of STEM learning together rather than each variable in isolation. The implications are that this project can provide opportunities to understand integrated subject knowledge and all of the aforementioned 4C's as an interconnected network that can be used to better understand the complex learning taking place in STEM activities.

This research project made use of audiovisual data to document the goings-on within selected non-formal STEM activities. This audiovisual data was collected by video recording the actions and conversations of three groups of learners within three different, yet thematically related, STEM activities.

These cases were selected based on the recognized importance of STEM activities for improving students' interest and performance in mathematics and science education. A report in 2022 outlined how Sweden undertook a number of initiatives to improve mathematics and science educational achievement by incorporating STEM activities within formal schooling alongside various activities taking place outside of the formal schooling system (Hartell & Buckley, 2022). The Swedish-based cases selected for this research project reflect this application of STEM activities, but specifically within the non-formal education sector.

The cases examined here were selected based on convenience due to a limited number of practical and hands-on STEM activities taking place within the timeframe of this project, and which were taking place in a non-formal setting in collaboration with formal tertiary-level educational institutions. Although there are many reported STEM initiatives within higher education institutions in Sweden, in addition to non-formal and ad-hoc STEM activities taking place in museums or organized by non-profits outside of schools, there is still limited cooperation amongst these various groups.

The cases examined in this research study were provided by one Swedish non-profit with links to the formal higher education sector. Three cases were made available for this research project and one group of learners within each of the cases were observed. The first and third groups consisted of five participants within each group and the second group consisted of only two participants. During each of these activities, the participants worked together to plan, design, build, and program a toy electric car. The audiovisual data of each group within the cases was analyzed to identify verbal and nonverbal ways that the participants referenced STEM subject knowledge or practiced any of the 4C's (communication, collaboration, creativity, and critical thinking).

This research used the a mixed-methods approach called Quantitative Ethnography (QE). Quantitative Ethnography allows for learning to be understood in terms of how connections are formed between various epistemics within the discourse of a learning culture (Shaffer, 2017). This QE approach combined the use of Epistemic Network Analysis (ENA) and Qualitative Document Analysis (QDA). An online analytical tool was used to generate ENA network models of the connections between subject knowledge and 21st century skills (i.e., the 4C's) to see what patterns resulted. A comparison of the networks for each group, and for each participant within each group, was conducted and connections that proved significant were identified. These network connections where related back to the original data (i.e., the videos) or the conversations (i.e., transcriptions) to gain a deeper understanding of how the connections in the networks could be understood in terms of their relationship to how learning is theoretically claimed to take place within a STEM activity.

The specific results of this research project are discussed in greater detail within the body of the thesis and so only a superficial overview is provided here. Several cautionary findings about STEM effectiveness were uncovered, and which aligned with the existing literature. First, it was found that the cases did not always provide a balanced integration of the four STEM subjects, and that mathematics was often the subject matter that was underrepresented. Also, the use of groupwork could be seen as a hinderance (in these cases) to how much each participant is afforded an opportunity to engage with all four STEM subjects and to apply all of the 4C's. For example, participants who were involved in the coding of the electric car showed different connections between skills and knowledge than the participants that were involved in other aspects of the activity such as building the electronics or designing the vehicle.

On the other hand, the cases also revealed information about how to improve the learning goals of the STEM activities. For example, each of the cases showcased behaviors and conversations pointing to rule-breaking that created the most prominent connections to creativity and critical thinking. The use of 'cheating' in these cases can be investigated further to determine its value in STEM education planning and design. Also, the networks revealed that the specific act of 'tinkering' (e.g., touching electronic components, playing with items to see how their parts worked, etc.) was highly connected with critical thinking. This finding suggests that STEM education that targets the application and growth of 21st century skills such as critical thinking may be helped by allowing for more tinkering and playful curiosity within its structure and design instead of focusing on successful project completion. Finally, this study also highlighted the role of instruction by showcasing how having an 'expert' mentor contributes not just knowledge to a group network, but also to the dynamics of how the 4C's were enacted by the learners.

To learn more about this research and its findings, please refer to the formal dissertation. It is hoped that this work will generate further conversations and developments in STEM educational activities, whether formal or non-formal, for learners of all ages.

1. Introduction

Education systems are constantly changing to reflect the needs and values of their respective societal contexts. Over recent decades, a growing trend within formal and non-formal learning has been the popularity and support of STEM-based education. STEM (science, technology, engineering, and mathematics) education is argued to reflect both the needs and the values of modern nation-states based on political and economic discourses of equality and global competitiveness within knowledge-based and technological industry. Global trends within many recognized knowledge economies, including Sweden, suggest declining interest and competencies within the related educational fields essential for participation within such modern scientific, engineering, and digital sectors—science and mathematics, in particular, suffer this trend (Eklund & Kult, 2024). Over the past decade, the discourses within politics, education, and the media have promoted the value of STEM education and learning environments for improving educational outcomes within science and mathematics while also invigorating the interests of students in primary and secondary school to pursue STEM into higher education and into future employment. In addition to the subject knowledge that is integrated within STEM, the added impact on the development and learning of professional soft skills (i.e., 21st century skills) is also trumpeted in connection with the use of more real-life, collaborative, creative, and active learning approaches (Kieu Nguyen et al., 2024).

The importance of STEM for both individuals and nations has promoted a body of research into evaluating and improving STEM teaching and learning. As the importance of STEM grows within political and educational discourse, there is an increased representation of research into STEM as a specified sub-field within educational research that has only grown in the past decade. Within the academic landscape there are now several journals dedicated to the topic of research conducted on STEM education, including just to name some of the most referenced: Journal for STEM Education Research; International Journal of STEM Education; European Journal of STEM Education; Journal of STEM Education: Innovations and Research; and the Nordic Journal of STEM Education. Many of these journals originated in the middle to the late 2000s following the popularization of the STEM discipline within the United State education curriculum in 2001. In addition to journals dedicated to STEM, there is a plethora of Discipline-Based Education Research (DBER) journals that archive and disseminate research on education and teaching within the separate subjects of Biology, Chemistry, Engineering, Mathematics, Science, and Technology. The categorization of DBER journals also accounts for specifications on the level at which these subjects are taught, and cover the scope of basic education (K-12) to postsecondary education and even non-formal and vocational education settings.

However, despite the growing interest in STEM as both an educational subject and as a topic of educational research, DBER focused on STEM education can run the risk of limiting the understanding of STEM learning if rhetoric and discourse on this topic assume the value and effectiveness of this educational trend as the inspiration or foundation for research into how learning takes place within STEM activities.

1.1 The Overarching Aim of This Study

This study aims to contribute to the STEM body of work by delving deeper into STEM learning by exploring the processes and interactions that take place between persons, and between persons and artifacts, within STEM activities. Specifically, these interactions and processes are focused on verbal and non-verbal manifestations of subject knowledge and 21st century skills in order to uncover networked patterns of interplay that may exist between these two facets. This research argues that understanding the interplay between subject knowledge and 21st century skills is important for understanding STEM learning as an engagement with the knowledge/cultural practice of a STEM activity.

When learning is conceptualized as a process of forming complex ways of thinking—rather than as an output represented by isolated knowledge constructs—it becomes possible to conceptualize STEM learning as a way of thinking and interacting within a knowledge/cultural community, and by way of these interactions creating meaningful connections between elements of knowledge and practice (Shaffer, 2017). This perspective simplifies the complexity of learning as an intricate phenomenon, and provides an opportunity to seek isolated events that can be interpreted as *conditions for learning* based on understanding these processes and interactions.

Therefore, the aim of this study is to provide an understanding of STEM learning—within the context of three non-formal STEM activity cases—that is based on the conditions for learning that highlight meaningful connections formed between subject knowledge and 21st century skills over the real-time course of the activity.

1.2 The Motivation for This Study

The aim of this research was motivated by a Latourian curiosity in understanding STEM learning "in action" and "in the making" (Latour, 1987). This motivation was inspired after repeated pilot studies brought to light the need for an evidentiary reinstitution of assumptions that frame STEM learning discourse as laudable for knowledge and skills development. This curiosity is the result of critically approaching literature about STEM education and uncovering an implicit *a priori* argument that STEM learning promotes subject knowledge and especially the development of modern workplace competencies. More importantly, much of the current research into STEM learning is often evaluating and measuring these *a priori* claims rather than establishing or testing them (see 3.6 Methods for Researching STEM Learning).

From this perspective, many of these *a priori* claims are related to the sorts of inputs injected into STEM learning contexts or activities (e.g., hands-on learning, problem-based learning, etc.) and their implicit connection with learning outputs. This research is driven by a curiosity in uncovering evidence to support popular claims about STEM learning as being positive for knowledge and skills development.

This project takes on a position reminiscent of Bruno Latour's *blackboxing* (Latour, 1999) when considering how the implicit merits of STEM education can hide the internal complexity of how inputs into a STEM learning activity context can be understood in relation to the outputs that are attributed to them. When presenting studies that evaluate the outputs of STEM learning activities, it is possible to detect a focus on inputs as the explanatory factors of the activities' outputs, failing to consider a thicker explanation behind how these inputs contribute. This motivation for the current research project does not devalue this body of work, but rather seeks to add another facet to building a greater understanding of STEM learning.

The focus on exploring the 'black box processes of STEM activities' allows for inputs to be understood in a more meaningful manner with respect to the outputs. Attributing more meaning to the processes within a STEM context permits a clearer explanation regarding how a pedagogical theory underpinning the selection of inputs can be supported as a variable in evaluating educational outputs. More importantly, this allows for a reframing of this emblematic learning system in a manner that places the black box at the center of the investigation rather than the variables on either end—i.e., inputs and outputs.

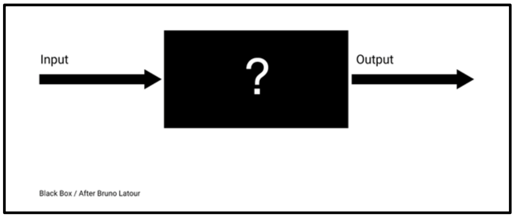

Figure 1: Black Box / After Bruno Latour
How Do We Know When We Know Something?. Boston University School of Public Health, News Article, November 5, 2017. https://www.bu.edu/sph/news/articles/2017/how-do-we-know-when-we-know-something/ Accessed 05-02-2025.

As a final note, the focus on processes aligns with rethinking STEM education beyond the limitations of *improvement science* and agentic conceptions of how actors in a STEM context are motivated and situated by this (Buxton et al., 2017). Furthermore, this allows for processes to be removed from the ontological sensibilities regarding debates about human and non-human actor influences, as well as offsetting the constructivist influences of networks as infiltrated by societal factors (Çetin & Demircan, 2020). When processes are stripped of these important (but in the case of this research, largely irrelevant) factors, the investigation into STEM learning within the context of STEM activities can be separated from the normative and social-economic goals of STEM education. The processes can be presented as formulated within the actions and interactions taking place within the compartmentalized context of the particular non-formal STEM activity cases examined in this study, and the individual participants within them. What this allows for is a closing of the analytical loop between what the evidence suggests about the cases, and how the specific verbal and non-verbal information of the participants represents this evidence. The STEM activities are therefore conceptualized as a knowledge/cultural community generated by the participants and the artifacts that they are comprised of. By identifying the verbal and non-verbal information that underpin the knowledge/cultural community, it is possible to close the analytical loop in understanding how the processes and interactions contribute to learning STEM knowledge and practicing 21st century skills as intertwined in one complex learning environment.

1.3 The Research Questions

What is apparent from this deliberate focus on the processes and interactions that take place over the course of a STEM activity, is that this project is driven by understanding and exploring the STEM activity cases rather than evaluating them with respect to STEM education best practice or learning effectiveness. This exploration targets identifying the processes and interactions that take place between and among the various actors, and between them and the artifacts in the context, in order to understand these elements in terms of how they can or cannot contribute to learning within STEM activities.

This focus provides a justification for the need to employ and evaluate a methodology that can bring processes to the forefront of educational research. By using a method that researches processes of learning, this investigation will work toward further informing some of the current learning theories that underpin STEM approaches to subject knowledge in science, technology, engineering, and mathematics, and the development of 21st century skills such as collaboration, communication, critical thinking, and creativity. What results from this focus are a series of four research questions that, when taken together, help to accomplish the singular aim of this study in being able to illuminate the black box of these non-formal STEM activities in service of helping to better understand how learning can be taking place.

The first research question focuses on the anatomization of the cases. This anatomization organizes the cases according to how connections between STEM and 21st century skills constructs are structured. These structures are then interpreted in terms of uncovering the processes and interactions taking place within the black box of the STEM activity. This question looks to identify conditions for learning in each of the cases and how this is framed within the knowledge/cultural community of the case anatomies.

The second research question compares the cases with each other, and compares the individuals within each case group. This investigation can extract distinctions in how conditions for learning manifest differently between cases and between individuals. The nuance of this comparison showcases how understanding inputs into a learning environment can be improved by being able to see how they manifest differently among cases and individuals. This can mitigate assumptions of causal influence attributed to any one input, by itself or in combination with others, when explaining STEM learning outputs. Also, a comparative examination of the cases and the individuals in each group case, can shed light on how the knowledge/cultural community of each STEM activity case is uniquely constituted by the processes and interactions among the various actors (human or non-human).

The third research question looks deeper into analyzing the specific connections highlighted by the epistemic network analysis, which displays cooccurrence patterns between STEM subject knowledge and 21st century skills, and takes on the added step of relating these patterns back to the source data. This deeper analysis is intended to close the analytical loop in understanding the learning contexts of the cases. This question redirects the discussion of STEM learning away from individual knowledge constructs and instead seeks to create an understanding of learning as based on how all of the facets cooccur. The subtle redirection of attention away from inputs toward how knowledge and skills manifest in the contexts, allows for framing the discussion of learning within how skills and knowledge cooccur and interplay.

Looking back to the source data to then see how these inputs and these manifestations are linked, can improve understanding of STEM learning beyond what each input and manifestation can do in isolation.

The fourth research question looks deeper into understanding how 'mentoring' and 'making' contribute to learning in these cases. Mentoring and making are two design elements of the selected non-formal STEM activity cases that were promoted by the non-profit organizers as being important for learning. The use of engineering student mentors and situating the cases within maker culture (e.g., within a makerspace) were established by the non-profit as inherently positive for STEM learning outcomes and the development of 21st century skills. These assumptions created two concrete *a priori* assumptions for STEM learning that could be examined based on their alluded presence and their impact on the pedagogical design and learning outputs of the activities. By looking at the conditions for learning and the knowledge/cultural communities of the cases, as influenced by these two factors, it is possible to examine how they are present in the cases, if at all, and how they can be attributed to learning.

Below are the specific research questions that were derived to accomplish the aim of this research project, and to drive the strategies, methods, and goals of this study:

1. What conditions for learning (i.e., processes and interactions) can be identified within each of the STEM activities examined in this study?

2. What does a comparison of the cases, and the participants within each case, communicate about the nuances of STEM learning in each context?

3. What does a network relational model of STEM subject knowledge and 21st century skills communicate about learning in each case, and how can this model help close the analytical loop in understanding STEM learning?

4. How do the roles of 'mentoring' and 'making' within each case contribute to STEM learning or the opportunities to practice 21st century skills for the various participants?

1.4 The Context and Testing of Methodology

The context of this study is based on information gathered from three cases of non-formal STEM activities organized by a non-profit with close affiliation to one of Sweden's prominent engineering schools. One group of participants from each case was the focus of data collection, and it is these three groups that serve as the case studies for this research. The three cases are conceptually linked and are presented as three separate iterations of one overarching problem-based learning (PBL) activity that has an integrated STEM focus. The amalgamation of knowledge from all four STEM subjects is crucial when tackling the complexity of the activities presented in each of the three cases, and highlights how knowledge and concepts from each subject can come together to provide a more holistic understanding of how to address the objective of the activity in each case.

The first case was situated within a two-hour hackathon with engineering students working in groups to build and program a vehicle that responds to a light stimulus. The second case involved a selection of two hackathon participants training to serve as mentors for a future offshoot activity based on the successful prototype created during the original hackathon. The third case followed one group of five Swedish secondary school teachers, and one engineering student mentor, building and programming a simplified hackathon prototype vehicle.

Digital video and audio data was collected from the one selected group within each case, and serves as the data source from which the analysis of the audio-visual interactions was conducted.

This research study employs an abductive approach to theory and methodology and is guided by a mixed-methods case study design that allows for an exploration of the data and the findings in a more holistic manner within the multimodal traditions of both learning analytics and thematic document analysis. Methodologically, the use of Quantitative Ethnography (Shaffer, 2017) brings together the various logical and design elements that have influenced the planning and progression of this research. This project aims to showcase the applicability of using epistemic network analysis, which is an approach and analytical tool derived from learning analytics research within the quantitative ethnographic tradition.

The application of this particular analysis aims to answer questions about the various processes and interactions taking place within STEM activities to inform and formulate answers to the research questions driving this examination. These interactions are documented and interpreted from collaborative, experiential, and problem-based learning perspectives that focus on knowledge and skills displays that include both verbal and non-verbal occurrences taking place among individuals, and between individuals and the artefacts present within their environments. Epistemic Network Analysis (ENA) can achieve this by modeling networks of interactions (i.e., relations) between objects and coded units of analysis within an analytic space that allows for comparisons between various models founded on the same stanza-based interactions (Shaffer, 2014). Examining these epistemic networks accommodates the analysis of complex relations that occur not just among, but also across and between, various relational interactions (Shaffer, 2014). The analysis from ENA provides a way to quantify qualitative data and add another layer of insight into informing learning theories underpinning STEM education.

Furthermore, this analysis of quantifiable relational data can be interpreted statistically to help illustrate what is taking place within an activity and its environment by potentially identifying statistically significant elements that can inhibit or contribute to learning. Therefore, this ENA approach allows for networks that identify constructs of both STEM subject material and 21st century skills manifestations to be mapped within a relational/interactional network that is dynamic and relative to the various stages that take place over the course of a STEM activity and the individuals participating in it.

To complement the quantitative analysis, a multimodal qualitative exploration of the same interactional data is conducted to enrich the findings that the former approach brings to light. This second level of analysis is a form of Qualitative Document Analysis (QDA), and it seeks to highlight what is communicated verbally or non-verbally during significant moments to thicken the understanding of how these moments can contribute to learning within the group contexts of the cases. The connection between trends in the data, and a deeper examination of what takes place in the isolated data associated with these trends, allows for a richer explanation of learning trends within these non-formal STEM activity cases.

The anticipation is that this combined mix-methods approach to exploring the cases in this study may contribute to an understanding of STEM educational activities that is based directly on participant conversations and their interactions with the physical components they are provided. Understanding STEM learning based on these interactional conversations and behaviors subsequently provides some insights regarding how to improve teaching and learning practice, while also shedding light on the unique elements of making and mentoring that are promoted within the particular cases explored here.

1.5 General Findings of the Research Project

Some of the key findings that this research generated can be applied to general design and delivery of STEM activities both within formal educational settings and when used by non-formal learning approaches. The use of a combination of ENA and QDA allowed for comparative networks to be generated within each case, which helped to tease out some aspects of the cases that could be examined deeper by returning to the source data with a qualitative lens. The results of the analysis showed that ENA provided a valuable manner by which to present the unique contextual relationships between STEM subject knowledge and 21st century skills, which would have otherwise not been accessible due to the large amount of observational and conversational data collected, or when using quantitative or qualitative methods alone.

The value of using methods that showcase relationships also aligns with the need to examine the STEM activity context as a complex, interrelated, and integrated learning setting. One focus of discussion on the application of STEM activities within formal educational settings is on the various facets to *integration*: integration of the four subjects; integration of a united and all-inclusive community of practice within an activity context; and the integration of knowledge and skills. The ability to investigate integrated learning contexts is an important factor for applying network analyses tactics.

The contribution of this research is aimed at providing more than just one more way of understanding and evaluating STEM activities as based on the particular cases from this one Swedish non-profit. This research is also conducted with a conscious effort to contribute to the growing argument for the use of more novel and technological analytical tools and methods within educational research. This position seeks to identify the challenges and opportunities that this route offers researchers in a modern era where digital interactions are ubiquitous and can offer another window into exploring and understanding the complex activity of learning when it is documented in a continuous or real-time format. That is not to suggest that all research into learning and teaching must move in the direction of computational and data-driven methods because not all studies will align with this approach. Instead, the methodological argument made here is dictated by the requirement for direct observational data of what takes place during the STEM activity instead of secondary interpretations of the activity by the participants.

This research evolved over the course of several years and underwent various iterations of methodological and theoretical evolution, including the use of self-report and pre- and post-test methods, before settling on the decision to focus on continuous data that can reliably display real-time information each time the data is revisited. Rather than focusing the analysis on data generated and gathered before and/or after a STEM activity has taken place, this research seeks to explore temporal data generated over the entirety of the activities in order to focus the analytical eye more objectively on what is taking place sequentially during the STEM cases.

The particular questions explored within the scope of this research highlight the shortcomings of evaluating the manifestation of knowledge and skills during STEM activities by relying on the limited and possibly unreliable information derived from participant self-report survey tools, pre- and post-test assessment, and intervention-style experimental methods and instruments. The application of a QE methodology utilizing audio-visual data proved difficult at times and fraught with practical challenges. However, the prospect of collecting richer information that could potentially contributing to a broader understanding of learning within STEM activities that can inform theoretical and assessment-based methods for evaluating the merits of STEM activities within formal and non-formal education made this effort worthwhile.

2. Background

The phenomenon of STEM education can be explored from various perspectives and using different frameworks. Although the exploration within this study approaches this topic from an educational point of view, the contextual implications that create the foundations for the importance of STEM within society and national economic policy and discourse cannot be ignored. Prior to elaborating on how STEM can be evaluated and understood within educational research, it is important to understand what STEM is and how it came about.

2.1 The Knowledge Economy & the STEM Pipeline

The evolution and ubiquity of digital technology has resulted in global markets moving away from industrial models of production toward knowledge-based skills and competencies to fuel and drive economic growth and development. According to the OECD, the trend "towards greater dependence on knowledge, information and high skill levels, and the increasing need for ready access to all of these by the business and public sectors" is termed the knowledge-based economy (OECD, 2005). However, not all knowledge-economies are the same; political systems, sociohistorical nuance, global economic standing, and even demographic realities can all impact upon how a knowledge economy develops, and by what aims it is driven (Sörlin & Vessuri, 2006). One case in point are the types of knowledge that are considered "valuable" or "powerful" within a knowledge economy, and which can be contextually determined and not subject to only generic competencies such as critical thinking or digital literacy (Harris & Ormond, 2019). This will have implications for strategies in identifying and pursuing particular orientations toward the harnessing of knowledge for the sake of national and global impact. Furthermore, although the shift toward knowledge-based industry is witnessed within both modern liberal democracies and some developing nations, each national context approaches the desire to supply the knowledge economy with skilled labor in a manner that aligns with individual policy, values, and needs (Bejinaru, 2019). No two knowledge economies are exactly alike, and neither are their historical and future trajectories despite similar aims or interpretations of what knowledge is to be lauded and how it is to be produced.

Despite these diverse ways of categorizing national knowledge-economies, in many instances, the transition toward a knowledge economy has resulted in pressure placed on the education sector to produce the skills and knowledge needed to promote innovation and national competitive advantage (Durazzi, 2019). This pressure comes about from ongoing gaps between labor market needs and the interests and skills attributed to educational output. There is an especial call for institutions of higher education to contribute with the knowledge and skills generated by both research and educational training, and which has positioned these institutions as both possessing greater societal prominence and yet more political accountability in their ability to drive and sustain a knowledge-driven economy (M. Singh, 2007).

Despite high rates of employment among many knowledge-related fields, there is still a general enrollment trend within tertiary education that suggests engineering, the natural sciences, and information and communications technology (ICT) fields are less attractive to students (OECD, 2017). The lack of enrollments within STEM higher education is contributing to a global shortage of skilled labor within a knowledge-based economy dependent on such careers (Bacovic et al., 2022). This economic influence on educational trends, and the stressing of global and national economic viability via identified educational fields of value and importance, is a discourse not uncommon when evaluating the output of education, or when motivating reforms within it (Hyslop-Margison, 2000). And, it is this discourse that, for better or worse, serves as the explicit foundation for the phenomenon under investigation in this study (i.e., STEM education) despite the obvious existence of critical discourses surrounding educational movements and trends that downplay the value of economic interests in order to promote social equality, equity, justice and cooperation (Gilead, 2009).

The role of economic discourse within educational policy frameworks and reform movements deserves a great deal of attention in its own right; however, the focus of this research study does not explore and evaluate systemic variables such as dominant societal discourses within education. However, an understanding of the milieu from which the STEM movement in education was derived is important to set the stage for its importance as a phenomenon of interest, and when establishing that the domains of education and the economy are to be constituted within a similar vein as regards the value and aims of STEM education.

This, of course, harks back to the dominance of human capital theory and the central role of the education sector within this theory. Human capital theory is very much infused into discussions related to skills and knowledge (whether subject knowledge or professional soft skills), which makes this connection explicit and one that cannot be ignored. Simply put, the skills and knowledge that are central to what makes STEM an attractive educational movement, and which are the analytical focus of this research, are also the same skills and knowledge that are promoted within economic discourses on knowledge-based economies.

The link between the economy and education as driven by the development of human capital remains a dominant societal discourse (Tan, 2014), and is linked to the analogy of the STEM pipeline. The STEM pipeline is the educational pathway that channels students toward STEM careers by way of STEM education. Although the education sector provides human capital for STEM industry, this does not suggest that student matriculation always meets these needs, or that all students are afforded equal access to education that feeds the STEM pipeline. Indeed, the pathway from education to a STEM career can have various instances where students turn away from the STEM career pathway. It is not uncommon to see traditionally disadvantaged students represent a higher proportion of those students that fall away from the STEM career trajectory, and with how critical evaluations for economic prosperity and participation in the knowledge economy are linked with an underrepresentation of women, ethnic minorities, and persons of lower socioeconomic status (Mendick et al., 2017). This disparity of disadvantage is reflected within STEM education and later into the STEM pipeline and through into STEM careers (Mendick et al., 2017). When continuing to use the analogy of the STEM pipeline, this lack of diverse and equal representation is referred to as the leaking STEM pipeline and points to the disproportionate dropping away from STEM education and careers of women and minorities (Liu et al., 2019; Makarova et al., 2016).

Ultimately, educational discourse about the value and contribution of STEM, as linked to the knowledge economy, is bolstered by the critical discourses within education based on demands for equity and equal access. This tacit support for the value of STEM (and the unfortunate implications for the devaluing of other sectors of the economy not encompassed within STEM and knowledge-based careers) is done based on the urge to address participation disparages among minorities who, via a leaking STEM pipeline, are segregated from the prestige and prosperity that is associated with STEM-based knowledge and high-skilled careers. This disparity is then transplanted into employment trends where disadvantage earmarks some students for the less prestigious labor-based skills or jobs that do not require higher-order technological skill-sets. Even when looking at critiques of STEM in terms of gender and minority representation, these critiques still reflect an economic rationale (Xu, 2015) that supports the ultimate foundation for STEM as being about economic rather than societal equity.

Before STEM can be conceptualized within a framework related solely to teaching and learning (i.e., STEM education), it is essential to understand STEM within this socioeconomic context and how this context impacts upon the conceptualization of STEM education. The association of STEM education with the types of careers dependent on knowledge found within one or more of the four subjects of STEM is portrayed as the STEM pipeline, which creates an analogy for a direct feed from formal STEM education into modern, knowledge-based occupations that require specializations within these subjects to participate in this sector of the economy (Brown et al., 2011a). As national economies continue to jostle for strength and influence within the global market, the issue of developing a labor force suited to complement modern economic demands and trends in the production and consumption of goods and services continues to manifest within discussions about education. Although there are various educational initiatives made to address this concern, the development and refinement of STEM education continues to be a topic of interest within economic discussions.

As mentioned above, formal educational discourse cannot fully disassociate itself from the role of the STEM pipeline, and how it establishes the importance for the STEM educational movement in fueling the knowledge economy. It is this supply-side evaluation of success that can sometimes overshadow and attribute value to STEM that can overshadow the educational perspective that evaluates its contribution to individual learning. STEM education runs the risk of becoming a teleological educational perspective when its value and success are based on this economic foundation alone. Within this research, the intertwining of economic and educational interests as regards the phenomenon of STEM education is simply taken for granted and set aside for the sake of focusing on the micro-level phenomena that take place within small learning contexts shaped by participants rather than socio-economic discourse.

From an educational perspective, understanding this educational environment and how both learners and teachers within it interact, is important to better understand how it is linked to learning in general, and which goes beyond a simple evaluation of whether or not teaching and learning in STEM is viable for maintaining the STEM pipeline alone. Although the association of STEM education with particular careers and with an educational movement driven to fill these vacant career positions is an important topic that drives STEM as an educational movement, this does not shed light into the actual connotation of how STEM education is formulated and delivered.

Simply put, understanding what STEM 'is' requires an educational perspective to present its main tenets and the learning theories that underpin the various approaches to how it can be evaluated as effective for learning—and not as merely effective for filling gaps in the labor market. The improvement of STEM education from both a teaching and learning perspective has proved important for all countries working to create, improve, or maintain their global competitive economic standing (Kennedy & Odell, 2014). This dissertation aims to contribute to better understanding these activities and environments to contribute to the body of knowledge about how learning in STEM takes place. This dissertation does not, however, serve to evaluate if STEM education is indeed having the desired systemic political and economic impacts associated with the growth and strengthening of a national economy.

2.2 STEM Education: Teaching & Learning

One system of educational reform driven by economic trends and discourse has been the development and promotion of STEM education and its related careers such as engineering, the natural sciences, statistics, and computer science (Yamada, 2017). However, although STEM can be seen as a formal *reform movement* within some schools and national contexts (e.g., the United States, Canada, and Australia), in other settings STEM education takes on less invasive forms and can be seen as *movements* based on interests from local schools, non-formal third parties/vendors, or smaller-scale regional and national initiatives.

The term STEM stands for "science, technology, engineering, and mathematics" and represents an integrated approach to the teaching of these four subjects across all grade levels and within both formal (classroom-based) and non-formal (education-allied) learning contexts (Gonzalez & Kuenzi, 2012). This acronym originates from the United States and is attributed to the National Science Foundation (NSF), who originally used the term "SMET" prior to adopting the more publicly appealing acronym of STEM in an effort to distance the subject matter from an unfortunate association with the word "smut" (Sanders, 2008).

Although many different definitions of STEM education exist, the one presented to the 70th Annual International Technology Education Association Conference captures how "STEM teaching and learning focuses on authentic content and problems, using hands-on, technological tools, equipment, and procedures in innovative ways to help solve human wants and needs" (Merrill 2009, as cited in Brown et al., 2011). This definition helps to draw attention to some key aspects of STEM that can be attributed to particular theories of learning that allow for a conceptual framework to be developed when exploring and evaluating STEM as a teaching and learning practice. The definition provided focuses on a relevant content that is explored with hands-on approaches and with the aid of technological tools. This conceptual framework will be elaborated upon in an upcoming section.

In order to understand STEM as an educational phenomenon more completely, a rubric that outlines the ontological, epistemological, and axiological domains help to present: 1) *what* is studied within STEM, 2) *how* STEM can be learned and 3) the reasons for *why* STEM is being learned (Chesky, 2015). By exploring these three domains of STEM, it becomes apparent how a diversity of opinions about this concept can abound, both with respect to how it is learned and taught, but also as regards the merits of its importance within education and society. The axiological domain of STEM has been addressed in the earlier section about the knowledge economy and the STEM pipeline. Reiterated briefly here, STEM education is driven by a belief that students will be better prepared for higher education and employment in STEM-sector positions if schools promote these subjects; that STEM careers are important is promoted within a national discourse of competitive advantage within a knowledge-driven economy (Brown et al., 2011b).

The ontological domain can be best understood as the integrated approach taken to seeing the four subjects that make up STEM (science, technology, engineering, and mathematics) as interrelated and comprising of subject matter that can both inform and be informed by the others. This integrated approach is often associated with greater and more formal curricular and institutional reform as opposed to less intrusive movements, even if these too adopt an integrated approach. This is highlighted with a separate reform specification of STEM called iSTEM (where the "i" refers to integrated STEM) and is associated with structural and institutional changes to teaching practice and classroom organization around the STEM subjects (Hodges et al., 2016; Owen et al., 2018).

The growth of interdisciplinary and transdisciplinary educational reforms is a trend seen throughout the world and is related to the current popularity of STEM movements and formal reform policies seeking to integrate various subjects (Bertrand & Namukasa, 2020). However, this does not promise that integration is balanced between the four STEM subjects. There is often greater focus on mathematical and scientific teaching and learning in STEM education (Honey et al., 2014) with more specific critiques being levied at the limited integration of technological tools and engineering elements (Breiner et al., 2012; English, 2017; Kennedy & Odell, 2014; Rockland et al., 2010; Wang et al., 2011). The cases explored in this research project place their focus on the latter two, often less integrated, subjects of technology and engineering, which may imply a more integrated STEM activity overall.

The final domain of epistemology regarding how STEM can be learned is at the heart of a larger debate into STEM and also a key aspect of this study. The definition provided above points to elements of an epistemological framework for what types of teaching and learning strategies are best employed. However, it is unclear how ideas behind this epistemological composition of STEM education were derived in relation to the more general learning theories that underpin them. Nevertheless, what is clear is that questions into how to teach and learn STEM knowledge and skills embrace more non-traditional strategies (Borda et al., 2020; Tularam & Machisella, 2018; Tuluri, 2017; Zhu, 2020) that aim at spurring interest in STEM fields and careers by making STEM subject matter fun, inspiring, and engaging.

Despite the growing popularity of STEM education over the recent decade, educational reforms and movements associated with STEM are still fraught with misunderstandings, inconsistencies, and a lack of clarity with respect to what unequivocally defines a STEM curriculum, activity, or environment. Many teachers struggle with integrating STEM into current curricula or accommodating the separate subject of STEM in a knowledgeable and confident manner (Margot & Kettler, 2019; Srikoom et al., 2018; Suwarma & Kumano, 2019). This ambiguity, however, is restricted to the precise details about what

STEM is (for example, varied opinions about whether STEM is a teaching practice, policy, reform, movement, or new curriculum), and is not carried forward to the overall evaluation of its importance among the opinions of educational experts, practitioners, policy-makers, and society at large (Slavin, 2016).

2.3 STEM Education and 21st Century Skills

When exploring the economic and political discourse of market competitiveness and knowledge-based skills within employment, the discussion does not only pertain to educational or technical competencies. The discussion surrounding STEM and modern workplace competencies also encompasses the value of teaching and learning 21st century skills (Jang, 2016). Although the sorts of soft skills and workplace competencies covered under 21st century skills are not always agreed upon, this study applies the framework put forward by the Partnership for 21st Century Skills to define some overarching definitions and components that are often present within the literature about 21st century skills (P21 Partnership for 21st Century Learning, 2019).

This framework presents the learning and innovation skills referred to as the 4C's: communication, collaboration, critical thinking, and creativity. Although each of these skills can be identified within the learning theories and approaches established at the foundations of STEM education, the last of the skills in this list, creativity, has been explored in even greater detail with respect to STEM education (Guo & Woulfin, 2016). In this study, creativity is also given extra attention alongside communication, collaboration, and critical thinking.

The same discourse that pushes the importance of STEM education is also putting pressure on STEM careers to align technical skillsets with more professional soft skills that promote greater success within knowledge-driven fields (Griffin et al., 2012). Put simply, a shift from relying on the use of one's labor to achieve occupational outcomes has begun to stress the importance for educational practice to promote new ways of thinking creatively and innovatively, and has placed greater focus on interpersonal skills such as communication and collaboration in better preparing learners for modern occupational success (Toheri & Haqq, 2019). This is true for STEM careers, such as engineering, as the body of work expands considering the need and importance of developing modern professional workplace skills to provide for more success in fields that traditionally focused on technical and cognitive knowledge rather than noncognitive soft skills (Badran, 2007).

Some initiatives to promote and adopt STEM education within the school setting have been driven not solely by the need to promote the STEM subject matter, but rather to use STEM education as a medium by which to infuse 21st century skills into instruction and student learning outcomes (Stehle & Peters-

Burton, 2019). The various interpretations and applications of STEM education do not necessarily undermine the incorporation of 21st century skills as a key component within the activities, environments, or curricula of STEM. Activities as diverse as Fermi problems (Ärlebäck & Albarracín, 2019), mathematical modelling (Maass et al., 2019), and exploring modern environmental issues (C. C. Johnson et al., 2019) are all delivered within the classroom with an explicit interest in acknowledging the ability of integrated STEM education to contribute to the fostering of 21st century skills. This does not only relate to educational activities within the formal sector. The diverse nature of STEM allows for non-formal STEM initiatives to also accommodate the integration of 21st century skills within their learning outcomes.

Linking STEM educational activities and environments with the ability to provide for 21st century skills development is one of the key themes driving this research. The conceptual framework for STEM education, encompassing the 4C's will be provided in an upcoming section.

2.4 STEM in a National Context: Sweden

STEM education originated from within the United States and was developed in a direct effort to combat declining interest and performance within primary and secondary education (U.S. Congress, 2013), as well as to address employment gaps based on poor university enrollment, within STEM-fields (U.S. Congress, 2014). However, despite the origins of STEM being embedded within the North American national context, the concepts and approaches often attributed to STEM have been adopted within various other countries facing similar educational and economic trends. This is witnessed especially within the application of STEM formal and non-formal education among the primary, secondary, and even early-childhood educational sectors around the world (Fan & Ritz, 2014). The push for STEM-driven reforms and movements within many countries is motivated by a similar discourse of global competitiveness and the need to remain relevant within an increasingly technological and interconnected global market. It is important to keep in mind, however, that the push toward developing knowledge-driven economies, and the adaptation of STEM education to compliment this trend, does not imply that both economic and educational policies and initiatives are identical between various countries.

The tendency to want to categorize all knowledge economies as being the same is dangerous, as is the manner by which this context is reflected in the education system. The dynamics of a knowledge economy are driven by contextual interplays between various social and institutional actors at both the macro- and micro-levels, and so it is important to recognize that the national context is important to elaborate upon. Assuming a homogenized interpretation of how a knowledge economy manifests and acts upon institutions such as education, whether formal or non-formal, can be faulty and misleading when making generalizations between different national contexts (Zeleza, 2007). This research project was situated within the national context of Sweden, and so a brief introduction to the features of the Swedish knowledge economy is presented below.

As stated earlier, global trends within many recognized knowledge economies suggest declining interest and competencies within the related educational fields essential for participation in modern engineering and digital sectors. This situation is similarly recognized within the context of Sweden, where the cases examined in this study are situated. Sweden presents a national context that is both committed to the evolution of a knowledge-based economy and yet aware of the educational challenges it faces in the pursuit of this endeavor. In the 1990s, the Swedish government actively promoted the transition from manufacturing to information and communication technology (ICT) sectors with the aid of supply-side institutions such as state innovation policies and educational reforms (Thelen, 2019). Even as early as the 1970s, the National Agency for Education (*Skolverket*) in Sweden has put forward a series of reforms targeting compulsory education from kindergarten through to grade nine with the goal of preparing students with the skills required for participation within a digitalized society (Heintz et al., 2017). Between the years of 2014 and 2018, a series of discussions and proposals for educational reforms focused on specific digital competencies related to programming and the integration of interdisciplinary approaches to the use of digital resources (e.g., tablets) and critical problem-solving within the classroom and during subject learning activities (Heintz et al., 2017; Otterborn et al., 2019). When reviewing the Swedish compulsory school curriculum, it is apparent that digitalization and modern skills are infused within subjects as varied as mathematics and language classes (Skolverket, 2018). The current importance placed on digital skills and competencies has had an impact on the increased availability of STEM educational resources and strategies, as well in light of the clear overlapping interests and subject matter respective to each.

However, what is less apparent within the Swedish context is the articulation of what can truly constitute a STEM educational curriculum or policy that is reminiscent of the framework outlined earlier. Despite a lack of literature about STEM educational reform or movements within the Swedish context, there is documentation about each of the separate disciplines of STEM being given priority and importance within formal education, and the increasing non-formal sector in taking on what are more obviously STEM educational activities outside of the formal education sector. For example, one of the key elements to STEM education is to motivate and inspire students to pursue and continue educational, and later occupational, trajectories within STEM fields. In Sweden, the educational reforms to science and technology from 1960-1990 were charged with a mission to make these subjects fun and "foster a scientific spirit" using practices of object lessons and experimentation that would interest students and allow them greater practical independence (Lövheim, 2014).

Also, the Swedish educational context has undertaken discussions about integrated subject teaching as early as the 1980s with debates surrounding integrated science education (Åström, 2007). The integrated approach to teaching the individual science subjects (biology, chemistry, and physics) as one integrated science subject is not unrelated to contemporary discussions about STEM and how the four subjects that comprise it are also interrelated and could benefit from being taught together rather than separately. Also important within the Swedish context is the emphasis placed on trends in student performance on international standardized testing such as TIMSS (Trends in International Mathematics and Science Study). The trend for Swedish students has generally been that of declining performance since 1995, which has resulted in long-lasting policy and media implications regarding improving student competence in science and mathematics (Nyström, 2013). Despite the connection between STEM and current educational reforms and trends in schooling being less concrete than what is found in other national contexts, Sweden still presents an interesting case for non-formal STEM educational initiatives sponsored and overseen by third-parties/vendors.

A recent study that critiques industrial engagement in STEM educational initiatives still acknowledges that about 40% of STEM activities in Sweden are offered or financed by the private sector and motivated by economic 'STEM crisis' discourses (Andrée & Hansson, 2020). The cases presented in this study are related to the non-formal education sector and the third-party/vendors providing ICT and digital workshop and resources to teachers and students. Also, a recent emergence of STEAM schools offering international curricula from North America and Britain have drawn attention to STEM even if formal overarching reforms to the entire Swedish curriculum have been less declaratively STEM-based.

Although the concept of STEM is only starting to become infused within contemporary discussions in Sweden, many of the reforms and trends in Swedish educational institutions reflect patterns and concerns that lay at the heart of the problems that STEM is meant to address. For these reasons, Sweden presents an interesting opportunity for investigating STEM despite the limited use of the formal term or acronym, which is growing year after year. As of the publication of this thesis in 2025, Sweden's Ministry of Education released information for the intended development of a STEM strategy (in Swedish: *STEM-strategin*) for the entire Swedish education system (Persson, 2024).

2.5 Is it STEM or STEAM, or Both?

Coming across various terms that refer to the same object of interest is not uncommon, even in research. As a concept evolves it can often take on various forms and specializations. The case of STEM education is no different (as noted earlier with the use of iSTEM), and is most pronounced with respect to the existence of both the STEM and STEAM concepts when referring to the same overall movement in education. While the former refers to the integrated and more student-centered approach to teaching and learning science, technology, engineering, and mathematics, STEAM incorporates another subject into the mix: Arts. The STEAM acronym (science, technology, engineering, arts, and mathematics) followed after STEM and has been argued to represent a more contemporary reaction to STEM ideology and foci, and can be referred to as a shifting educational paradigm in integrating the arts into current STEM subjects (Bertrand & Namukasa, 2020).

However, when looking into what distinguishes STEM from STEAM, with the exception of superficial references to artistic elements (e.g., using arts materials or creating artistic rather than merely technological artifacts), the inclusion of Arts refers to aspects such as making, design, creative and complex problem solving, and utilizing transferable skills such as the 4C's (communication, collaboration, critical thinking, and creativity) (Thomas & Huffman, 2020). These are elements present within current STEM pedagogy, and results in a rather superficial and narrow distinction between STEM and STEAM that makes the delineation of STEAM meaningless. Furthermore, the cases explored in this research project incorporate both superficial and deeper aspects of the Arts, but do not make them a formal or conspicuous part of the activity as separate from what is already a part of modern scientific and engineering design and thinking.

However, there is a tendency within the STEM research literature to conflate the two acronyms and contribute to further debates about how to distinguish between them, if at all, or how to decide which concept is to be carried forward in STEM education discourse. Many journal articles will include both STEM and STEAM within keyword or subject headings and often conceptually link them together with an oblique stroke (i.e., "STEM/STEAM").

Within this dissertation, only the STEM acronym is used even if one could argue for the use of STEAM together with STEM, or even entirely in its place. As stated earlier, the distinction between STEM and STEAM within the pedagogical design of STEM activities that are hands-on and "fun" does not distinguish the subject area of Arts in a manner that sets it apart from the goings-on within STEM activities to warrant its inclusion as an additional formal subject.

3. Previous Research & Theoretical Discussion

This study seeks to look inside the black box of learning for three non-formal STEM activity cases in order to understand the conditions for learning of both subject knowledge and 21st century skills. To frame the complex phenomenon of learning, this research examines the black box using a STEM conceptual framework that is embedded in the learning theories and concepts that have informed STEM discourse. This section presents a coherent and concise organization of the concepts and learning theories that are embedded within STEM education literature and which are most applicable to the STEM activity cases investigated here. This theoretical framework allows for a clearer outline of how the cases within this study can be understood and researched. Also, an overview of the STEM objects of learning regarding subject knowledge and 21st century skills are defined and operationalized. Finally, this section also presents a brief overview of the literature that evaluates STEM effectiveness for learning, which was the motivating factor that drove the initial direction of this study, and which was later abandoned in favor of the current approach.

A limited overview of the most recent literature evaluating STEM activities and their influences on learning outcomes is also presented. The purpose of this critical review is to provide evidence for claims about how academic work into STEM learning tends to extrapolate semi-causal effects of measured learning outcomes from theoretical STEM learning strategies, and how this is done without establishing this association within the analyzed data, or with performative evidence of these learning strategies enacted over the course of the STEM activity itself. What is sought within the literature is an identification of an analytical step toward closing the research loop into STEM activity effectiveness that does not rely on explanations of learning outcomes based on pedagogical theory alone. This is done by identifying within the data specific contextual processes of the activity that can connect learning outcomes with specific aspects of the STEM learning framework that reflect the pedagogical theories underpinning the design of a STEM activity.

Using this existing literature to understand the processes and opportunities for learning STEM subject knowledge or enacting 21st century skills establishes the groundwork for identifying what is of interest when attempting to understand learning within the STEM activity context. This research attempts to peeks into the ‘black box’ of learning using quantitative ethnographic methods that target processes and conversational interactions that can help elaborate on simplified models of learning framed by vague casual associations between inputs (e.g., teachers, resources, tests, etc.) and outputs (e.g., knowledge, competencies, improved test results, satisfaction, etc.) (Black & Wiliam, 1998).

3.1 The STEM Conceptual Framework

The definition of STEM presented earlier highlights the following major components of STEM education: authentic content and problems; hands-on activity; the use of technological tools, equipment, and procedures; innovation; and relevant topics based on human needs and desires. These components allude to the constructivist learning theories of Piaget and to inquiry-based approaches when looking at the integrated learning of STEM subject matter. Constructivist and inquiry-based approaches to learning can be found within the canonical works that establish the foundations of many educational learning theories, especially those of science and mathematics teaching (Abd-El-Khalick et al., 2004; Chesky, 2015). Furthermore, specific approaches such as active learning, project-based learning, collaborative learning, and experiential learning provide valuable concepts for developing a framework to conceptualize and investigate STEM activities from a learning perspective. Lastly, the learning of 21st century skills are also underpinned by learning theories that need to be incorporated into the overall framework while recognizing that the core 4C’s skills of communication, collaboration, critical thinking, and creativity are themselves tools within the STEM activities, and are learned and improved upon by nature of their incorporation into the framework. In the upcoming section, Learning Theories and STEM Education, it will become clearer how these elements are essential for the learning process, and why they are considered essential for the success of STEM educational approaches. Specifically, the framework presented here allows for a way to move away from attempting to define and understand STEM education, and instead constrains the conceptual framework to STEM activities in particular, which are only one fragment to STEM education.

3.1.1 An Integrated Approach

As the acronym STEM implies, the four subjects that compose it are considered not as separate subjects, but rather as one integrated subject. That is not to suggest that STEM activities must include all four of the subjects within an integrated activity at all times. In many instances, so long as at least two of the four subjects are represented, the activity or curriculum qualifies as STEM education (Gonzalez & Kuenzi, 2012). However, it is still difficult for teachers and educational curriculum designers to find a fully integrated approach to a truly multidisciplinary STEM education that incorporates all four subjects (English, 2017; Srikoom et al., 2018). Despite the intuitive link between science and mathematics, and their easier integration into pedagogical problems and projects, other subjects within STEM, such as engineering, become more difficult to implement and incorporate into grade-school (K-12) classrooms, which often leaves students unprepared for the integrated nature of studies in higher education and later in STEM careers (Rockland et al., 2010). The use of technology is also considered to be a difficult element to integrate into the classroom even if teachers are provided with professional development geared at STEM integration (Wang et al., 2011). What results is that STEM education tends to reflect scientific themes that are linked to mathematical principles, as per a more traditional and standard classroom curriculum, that sometime can use technological tools and inspiration from engineering design. It is rarer that STEM in the classroom takes its starting point from the latter two subjects (technology and engineering) and then builds scientific and mathematical principles and lessons around them.

The full integration of STEM as one multi- and interdisciplinary subject is still difficult to achieve without proper support for teachers in understanding the interconnectedness of engineering and technology with science and mathematics, and is still the subject of research and curricular development (Bybee, 2013). The cases explored in this research project, although not professionally designed and situated in a non-formal learning setting, begin the planning of the STEM activities from the incorporation of engineering and technology and later refer to the associations with science and mathematics. For this reason, these cases offer a glimpse into STEM activities that not only offer a more complete integration of the four subjects, but which also stress the often-overlooked aspects of STEM when such activities are conducted within formal classrooms, or are incorporated into a formal lesson plan on science or mathematics.

3.1.2 Authentic Contexts and Real-World Problems

Abstract and unrelatable questions and problems are not uncommon when looking into school textbooks on mathematics and science—surely the ubiquitous memes about "the guy from the math problem" are relatable to many persons reminiscing about unrealistic scenarios concocted to test mathematical knowledge. However, it is becoming increasingly popular, especially in science, computer, and engineering education, to structure learning around real-world problems that students can relate to, and which have implications and relevance for current events and modern challenges that students face outside of the classroom and beyond their summative assessments (Abbott et al., 2020; Cantrell & Through, 2019; James Ferreira et al., 2018). The use of real-world problems is also relevant within STEM, and is incorporated into the very definition of what STEM education should include (Breiner et al., 2012). Examples of real-world problems can range from framing activities and projects around pressing modern issues such a climate change and tracing weather patterns, or creating simulations of authentic challenges faced on a larger scale by society or companies (Glancy & Moore, 2013).

Authentic contexts and real-world problems are associated with the use of problem-based learning in light of how relevant subject-based concepts are used in relation to scenarios that should reflect problems that are tangible and real to learners (Savery & Duffy, 1995). However, it is not always clear if this is all that is needed for effective learning, and some critiques have suggested that as long as the process of problem-solving is authentic and reflective of how a similar problem is solved in the real world outside of the classroom, that focusing on pure authenticity and real-world scenarios can actually not promote better learning for novice learnings still coming to terms with developing the skills to effectively problem solve (Herrington & Herrington, 2006). That is, there can be debate about whether authentic contexts and real-world problems contribute to more effective learning of subject knowledge. However, this debate does not address the possibility of such methods in promoting greater interest and motivation to learn, which can also be important for learning. Despite this possible critique, the STEM activities investigated in this research project embrace the need for authenticity and connection to real-world problems. For example the hackathon included a third-party industry representative responsible for the BBC Micro:bit to assess the application of the device for use in education by way of student feedback, and the three cases together all used simulated solar power to help train programming and design.

3.1.3 Hands-on Activities (i.e., Making)

The creative and functional production of artifacts is not a new phenomenon within the history of mankind. The evidence that humans have been making things for over 2.6 million years can be witnessed by the countless stone tools found at sites of prehistoric human habitation. The need to create, whether for ritual or utility, cannot be ignored when considering the evolution of human society and ingenuity. In today's modern era, the need to create may go beyond these rudimentary beginnings but the drive to create remains the same.

Hands-on activities within STEM education take on the role of what can be called "making" (or in less formal terms, "tinkering"). In contemporary literature, the concepts of the maker movement and maker culture have become associated with a focus on STEM education in a way that is engaging and which appeals to the creative thinking of students of all ages, even if making and the individual subject matter of STEM are not clearly aligned from a pedagogical point of view (Marshall & Harron, 2018). Furthermore, the injection of maker culture into formal education, and especially external stakeholders with access to equipped makerspaces, has targeted STEM education at all levels with the promise of hands-on problem-solving learning opportunities (Tabarés & Boni, 2023).

The aspect of "hands-on" learning within STEM, and within the particular activities explored in the contexts of this study, is a key component of enriching the learning experience of participants within STEM activities, environments, and curricula. The act of making, whether via programming or prototype fabrication, allows for students to guide and develop skills and practices for solving problems in a self-directed and collaborative manner by being creative and innovative, and by taking on the roles of designers, scientists, or engineers (Martin, 2015). The act of making also contributes to making the experience of the STEM activity more relevant, enjoyable, and satisfying, and for making learning more tangible (Hsu et al., 2017).

However, it can sometimes be difficult to align a maker pedagogy of learning with a less progressive formal educational setting that works with more rigid teaching and assessment cultures, and which may lack an integrated STEM curriculum (Halverson & Sheridan, 2014). Also, the cost of hands-on education can sometimes make this approach unreasonable for schools or teachers, especially if there is an expressed need for a formal makerspace stocked with expensive fabrication gadgets like 3D printers, electronic components, and industrial power tools.

The cases explored in this research project showcase how cooperating with a third-party (i.e., a non-profit and a school development program) can bring the making aspect into more traditional settings that would otherwise not engage in STEM education. However, this cooperation also comes with concerns over the role of third-parties within formal education and the challenges educators face when this collaboration is not always a smooth one (Tabarés & Boni, 2023). Although this critique is not central to this research project, the role of third-party stakeholders in the cases examined here do have implications for how the STEM activities are designed and implemented. The most obvious examples are addressed by one of the research questions that seeks to investigate the predetermined pedagogical inputs such as the use of engineering students as mentors, and situating the activities within an equipped makerspace environment.

When examining the concept of making within the scope of the three non-formal cases of this research project, the goal of the STEM activities to produce a real-life, three-dimensional, technological artefact results in the act of making being an integral part of the activity design and purpose.

3.1.4 Incorporation of Technology

The use of technology in STEM education is another key aspect that strives to align this educational movement with the modern, digital, needs of society. However, as mentioned earlier, the incorporation of technology is sometimes lacking when compared to the attention paid to mathematics and science education within STEM. The role of technology in education can have various foci including whether or not technology makes education more democratic and personalized, or whether the role of technology in the classroom is geared toward commercial and economic goals related to the needs of navigating a modern digitalized society (Selwyn, 2016).

The exact presence and use of technology are also quite varied. Some inclusions of technology into learning institutions or environments include the use of learning management systems by teachers and institutions, or the shifting of education to online/e-learning platforms, or to the simple provision of technological tools (e.g., tablets, smartphones, computers, digital textbooks, etc.) as mediators for educational practice (Mlitwa, 2007). With respect to STEM education, the main idea behind the incorporation of technology is that it provides another avenue for the sorts of hands-on activities that are promoted by constructionist influences on the inclusion of computational activities (e.g., Papert's Logo Turtle or Lego Mindstorms) into STEM learning activities (Csizmadia et al., 2019).

In STEM education, the role of technology is either embedded and integrated into an activity to be used to creatively solve problems in a self-directed manner, or it is used as a tool to facilitate or enrich problem-based learning via basic task performance (e.g., word processing), or as part of a collaborative online application or digital simulation (Akgun, 2013). The use of technology within STEM also supports the development of 21st century skills, such as social skills and critical thinking, while also promoting digital literacy and competence (Dogan & Bernard, 2015). The use of technology in STEM is also linked to an improvement in access to constructionist and cooperative learning environments and promote learning of this nature that is aligned with the overall hands-on, experiential pedagogy espoused within the problem-based learning of STEM (Bottino & Robotti, 2007).

The activities encompassed by the three cases in this project use technology in both an integrated fashion, but also as tools for interaction and task performance. For example, the integration of technology applies to the use of electronic components to build the vehicle prototype, and the use of technology as tools is related to the use of computers or mobile devices to write program code, look up information online, or even to create a light source for the light sensor to detect.

3.2 Learning Theories and STEM Education

The very foundational principles of STEM learning can be found within the classical literature and contemporary works of psychology, the learning sciences, and philosophy. Much of the foundational learning perspectives on STEM education are situated within an almost unified constructivist learner-centered paradigm tracing its routes to influential educationists such as John Dewey, Jean Piaget, and Lev Vygotsky (Shah, 2020). Additionally, STEM education is also influenced by more contemporary figures such as David Kolb and his formulation of experiential learning (Kolb, 2015) and Seymour Papert with his Piagetian ‘constructionism’ influence into modern maker, technology, and computational learning approaches (Ames, 2018; Harel & Papert, 1991). Within the STEM literature into learning, it is not uncommon to find several, if not all, of these names mentioned as keystones to the strategies incorporated into STEM classrooms and activities. For example the work of Dewey overlaps ideas from collaborative learning and experiential learning with two key components of his writings on learning, such as mentioning the importance of social interaction and emergent and creative reconstructions of embodied experiences that are enriched through the act of reflection activity (Thorburn, 2020). It is, therefore, rather difficult to attribute much of the canonical works to any one contemporary learning perspective on STEM education.

An overarching constructivist perspective on learning as a social and active endeavor is subtly incorporated into STEM education, which moves away from the more traditional teaching and learning strategies that place the focus on teacher-lead instruction and passive student learning. Within the literature on effective STEM teaching and learning, the adoption of active learning strategies that move away from traditional teacher-centered instruction seems to be favored for their promotion of critical thinking and motivation on the part of the students to engage with their own learning (Zhu, 2020). For this reason active learning becomes a rather overarching concept under which many of the learning perspectives can be placed due to its association with supporting higher order thinking that is often accomplished in collaborative settings with self-directed inquiry and complex multimodal techniques to solving problems (Kressler & Kressler, 2020).

Taken together, the constructivist theoretical underpinnings for conceptualizing STEM learning within the context of STEM activities is highlighted by collaborative learning, experiential learning, and active problem-based learning.

3.2.1 Collaborative Learning

Collaborative learning has been studied by various educational and psychological disciplines with differing theoretical and methodological perspectives, which can make it difficult to find coherent and unified literature of the subject (O’Donnell & Hmelo-Silver, 2013). This project has adopted a conceptual definition of collaborative learning defined by what is needed for it to be considered an effective learning strategy. According to this perspective there are five elements to effective collaborative learning: 1) positive interdependence;

2) face-to-face promotive interaction; 3) individual accountability; 4) interpersonal and small-group skills and; and 5) group processing (Johnson & Johnson, 1991). Of these five, it is the importance placed on small-group skills that is most interesting when exploring STEM activities that take place in peer groups with the help of mentors.

The key to effective collaboration is successful social interaction and an understanding of key 21st century skills such as communication, in addition to being able to resolve conflict and make decisions (D. Johnson et al., 1998). With a focus on communication, the use of an information processing approach to collaborative learning is suited to looking at the promotion of learning by how students process information that is conveyed in communicative dialogue (Webb, 2013). This is especially related to the use of epistemic network analysis and its focus on discourse and relational stanzas.

Collaborative learning embraces the social psychology of both Piaget and Vygotsky as either focusing on, in the former case, the influences of peers as equals with opportunities to influence each other, and in the case of the latter, as a distinction between the zones of proximal development present in unequal collaborative relationships between more capable and less capable persons (O'Donnell & Hmelo-Silver, 2013). Each of these perspectives are relevant to the two types of collaborative dynamics present within the cases of this research project. Piaget can better relate to peer group dynamics among the STEM activity participants while Vygotsky can better relate to the collaboration between mentors and the STEM activity participants.

3.2.2 Experiential Learning

It almost goes without saying that people learn from their experiences, whether in life or in more structured contexts. This has resulted in what is often termed "experiential learning". Although learning from experience can be traced back to the ideas of John Dewey, the most prevalent name to be associated with experiential learning is that of David Kolb. That is not to say that his model for experiential learning has gone without dispute. The most famous of these critiques was put forward by Peter Jarvis with his desire for social contexts to be better addressed in Kolb's original model, resulting in a dualistic ideological thinking about how experience, reflection, and context intertwine to promote learning (Kuk & Holst, 2018).

Despite these differences of opinion and the countless ways to reimagine the model first put forward by Kolb, the basic tenets to adhere to are how the processes of experience and reflection come together to promote learning in a STEM context. For example, one engineering course adopted the four-stages of the Experiential Learning Cycle (concrete experience, reflective observation, abstract conceptualization, and active experimentation) to attempt to make experience actually *count* in the learning process (Bertoni & Bertoni, 2020). Because STEM education deviates from more traditional teaching strategies, the use of experiential learning is more aligned with the open and cyclical inquiry found within the learning processes associated with experiential leaning such as learner-centered, constructivist, project-based and collaborative learning (Matriano, 2020).

However, it is not enough to dogmatically suggest that experiential learning is *ipso facto* a part of STEM. It is important to be able to witness the learning process take place in order to determine if STEM learning is indeed helped by this learning model, or to determine if this way of learning is inherently present within the methods and strategies employed in STEM education. Although it is unclear if experiential learning is indeed present within the cases explored in this study, and if so to what capacity, applying the four-stage model is one possible way to account for its presence.

3.2.3 Problem-Based Learning (PBL)

The use of terms like problem-based learning (PBL), project-based learning (PjBL), and inquiry-based learning (IBL) are seen within the STEM literature in a manner that can muddle the distinctions between them. For the sake of this research project, the PBL term is used instead of PjBL or IBL as the former relates better to student-centered inquiry into real-world problems, and require less emphasis on teacher involvement as in the case of inquiry-based learning or project-based learning (Oguz-Unver & Arabacioglu, 2014).

Problem-based learning is yet another buzz word found within the STEM literature and is associated with core aspects of STEM education such as inquiry into real-world problems and experience-based education (Cindy E. Hmelo-Silver, 2004). Some of the more notable applications of STEM within the formal classroom setting employ the Purposeful Design and Inquiry (PD&I) approach, which brings together technological design and scientific inquiry, or a form of Problem-Based Learning (McComas, 2014). Other literature espouses the merits of PBL and its use in fostering collaborative and self-directed learning (Savery, 2006).

To identify PBL within a STEM activity, six core principles should be present: 1) a learner-centered approach; 2) small group work; 3) teachers working as mere facilitators; 4) solving authentic and real-world problems to promote learning; 5) the development of soft skills such as problem solving; and 6) self-directed learning (Barrows, 1996). However, the demands that these six principles place on teachers and institutions to design and incorporate PBL into classroom or formal instruction makes it difficult and time consuming to implement (Lee & Blanchard, 2018). Of course, this is the same challenge that faces the incorporation of STEM curricula and the effective teaching of it in general.

The main goal of using problem-based learning within STEM activities is to improve problem-solving skills in light of their association with the needs and demands of success in STEM careers and higher education (Euefueno, 2019). The STEM activities in this research project all began with questions that the groups had to solve on their own with the help of mentors. To determine if PBL is truly an effective tool in these STEM contexts, it is important to determine the nature of the problem-solving that took place over the course of the activities.

3.3 A STEM Activity Learning Framework

When combining the STEM conceptual framework and the STEM learning theories, it is possible to organize these elements into an overall STEM learning framework (see Figure 2). This STEM learning framework is specific to the non-formal STEM activities examined in this research project, and highlights elements that can sometimes be excluded or underrepresented within formal education that does not use STEM activities in the classroom. For example, the non-formal STEM activities examined over the course of this research project employ collaborative groupwork, 'making' practice to produce a physical prototype, and this prototype is built using technological tools such as electronic components and a computer programming interface.

Within these types of activities, it is possible to identify learning strategies that are promoted as favorable to learning. One of the hallmarks of STEM education, and one of the more lauded pedagogical strategies according to teachers of STEM subjects, is that of active learning, which incorporates the use of hands-on experience when solving authentic problems (Zhu, 2020). This is often a common feature found within frameworks for what STEM education, by definition, emphasizes within the design of its activities. What is meant by "hands-on" and "authentic problems" can be open to some interpretation, but it is easy to see examples of these strategies within the cases explored in this study. The use of hands-on learning is seen in less traditional classrooms and can be attributed John Dewey's progressive education that promoted a learning-by-doing approach that is seen in more learner-centered and authentic learning environments (Williams, 2017), which are the key elements of a STEM learning framework.

When considering the STEM learning framework in a manner that incorporates the conceptual framework into the learning theories, it is possible to reinterpret the key pedagogical aspects of the STEM activities examine in this research. The STEM activities become indicative of experiential (hands-on, integrated, technology), collaborative, and (hands-on, integrated, authentic, technology) problem-based learning.

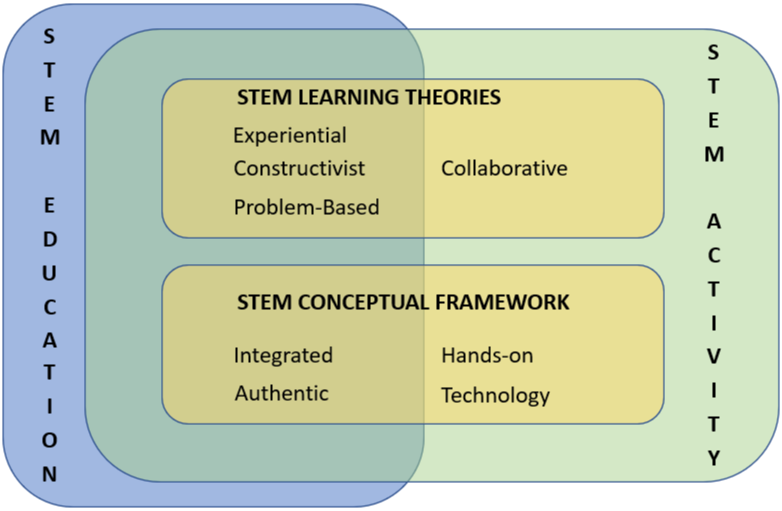

Figure 2
A STEM Learning Framework Featuring STEM Activities

3.4 Research and Practice for STEM "Effectiveness"

Some branches of educational research are devoted to an exploration of how to investigate, understand, and evaluate the process or outcomes of an activity referred to as *learning*. Although much can be said about the gap between decision-making in educational practice and policy, and the findings and suggestions made within educational research publications (see for example, Tunison, 2020), there is still a need for informed approaches when adopting or justifying the use of newer curricula or pedagogies.

The relative novelty of STEM as an integrated curricular approach or school subject is just one case where research can help inform practice. However, from the perspective of educational research, it is important to understand how practice has been evaluated to better understand how the development of STEM education can take place, and to understand the sorts of discussions present within the educational community when it comes to STEM effectiveness and its value for students and teachers. The sorts of strategies and pedagogies that are associated with optimizing learning are not entirely different within STEM education when compared with other general approaches to learning within K-12 or even within higher education. What is somewhat different is the focus on effectiveness as a benchmark for the evaluation or researching of STEM education and STEM activities.

When it comes to the research-practice gap, there are quite a few partnerships, knowledge brokers, organizations, and institutes that serve to promote and organize information about why a particular educational method or strategy is effective, and how to ensure best practice (Tunison, 2020). Within Sweden in particular, knowledge brokering occurs most often among governmental agencies such as The National Agency for Education (*Skolverket*) and the Swedish Research Council (*Vetenskapsrådet*), with lesser activity from private brokers as is the case in other countries (Wollscheid & Opheim, 2016).

This use of knowledge brokers is especially important for STEM within the American context, but this subject and curricula has only gained interest in Sweden in recent years with the Swedish Research Council making especial note of funding grants targeting exploratory investigation into STEM in 2020. According to the OECD, an institution that itself if often referred to as a knowledge broker, when it comes to research into STEM education, there is special importance on the use of "research-practice partnerships" (RPPs) to promote the value of non-formal and informal learning environments, and other tenets of more active learning strategies within the STEM framework (Kuhl et al., 2019). It is often these RPPs that offer insight into how to identify elements of STEM education, such as effectiveness, that can become the focus of educational research and practice.

The following discussion explores some of the key aspects of STEM education that have been adapted into educational practice as based on the dictates of RPPs in terms of a STEM framework and effective pedagogies. It is the aim of this study to determine, using observations of real-time STEM activities, if the ideas put forward by STEM knowledge brokers, driven by macro-level concerns about modern/digital economic competitiveness, can be explored within non-formal STEM activities and based on evidence rather than theory or allegorical assumptions of pedagogical strategies for more active learning.

As stated earlier, defining what STEM education is, and what framework of teaching and learning strategies encompass it, is a matter of expanding debate based on the overall interest and position taken on what STEM educational outcomes are meant to be. For the sake of this study, several hallmarks have been identified that can be explored based on contemporary theories of learning (see Figure 2).

When delving into the literature on STEM, there are a number of common themes that are often the focus of debate and examination into STEM effectiveness, which include: what learning and teaching strategies to employ when designing and implementing STEM education and STEM educational activities; the use of an integrated approach in teaching each of the four subjects of science, technology, engineering, and mathematics; and lastly, STEM education often demands (based on the integrated approach mentioned earlier) that teaching and learning incorporates the use of digital tools and resources to improve modern technological competencies. Each of these aspects can be subjected to investigation from both a theoretical perspective into understanding their foundational assumptions and claims, and from a methodological perspective that helps to identify how research into the teaching and learning within STEM education can be evaluated and assessed based on effectiveness.

3.5 STEM Education and 21st Century Skills

In recent years, the importance of 21st century skills have been promoted by both the education and business sectors as modern careers and workplaces require more than mere subject knowledge and technical know-how (Levy & Murnane, 2004). Although the incorporation of 21st century skills into learning contexts is not solely taking place within STEM, the learning strategies and environments often designed for STEM activities allow for complex thinking and social skills such as communication to be coupled with the use of digital tools and creative design. The more prominent role of 21st century skills within STEM education can be attributed to the common practice of using social and global problems to underpin activities and lessons, which promote the use of intellectual skills such as adaptability, non-routine problem solving, self-management, and systems thinking in order to address the sorts of challenges presented by such activities (Bybee, 2013).

Furthermore, the sorts of learning activities present within STEM education can be likened to the manner by which technical skills are acquired in the workplace alongside intellectual, 21st century, skills (Levy & Murnane, 2004). For these reasons, although the importance of incorporating modern and professional skills into student learning is not an uncommon practice, it is greatly intertwined with the fabric of how STEM education is designed and delivered. For example, one study utilized a STEM approach inside a makerspace for the promotion of 21st century skills such as problem-solving, critical and creative thinking, collaboration, and communication in grade-school girls and found positive results in their uptake (Sheffield, Koul, Blackley, & Maynard, 2017).

Despite the links between STEM education and 21st century skills development, there is still a gap in labor and industry needs because it is not clear if the types of skills that are targeted by STEM education are those that are truly being learned, or that they are the types of skills even desired by eventual employers (Jang, 2016). Another study on workplace needs revealed that many of the 21st century skills demanded by employers were dependent on other factors such as type of job and education levels, which suggests that STEM industry demands may differ from general employment (Rios et al., 2020). Despite the specific needs of STEM industry, the sorts of skills that are embedded within the STEM educational framework, and the learning theories that underpin its pedagogical practice, do work toward fostering greater 21st century skills regardless of whether or not all STEM competencies are addressed.

Furthermore, the integration of STEM into one subject, and the integration of selected 21st century skills into one framework such as the 4C’s, can be further combined to integrate these two elements into a learning model that can better prepare students for the modern workplace by using STEM education to target the development of 21st century skills (Dewanti & Santoso, 2020; Herianto et al., 2024). The research and learning models that take on this approach utilize STEM education as a vehicle for 21st century skills development and assessment due to the effectiveness of this approach (see Kousloglou et al., 2023; Yalçın, 2024). The combination of using STEM education with teaching and learning strategies that are meant to improve or develop 21st century skills highlights how these two elements are interconnected within modern workplace contexts.

3.6 Modern 21st Century Skills and the 4C's Framework

The skills that are the focus of this research project are communication, collaboration, creativity, and critical thinking, which are part of a framework developed by the Partnership for 21st Century Skills (P21). These skills are lumped together in what is referred to as the 4C's and are labeled as learning and innovation skills, which are considered essential for preparedness for modern work and societal life (Partnership for 21st Century Skills, 2011). These skills can be clustered under domains similar to the categorization found within Bloom's taxonomy where critical thinking and creativity belong under a cognitive skills domain and communication and collaboration fall under an interpersonal skills domain (J. Pellegrino & Hilton, 2012).

Classifying skills, and even developing teaching strategies to incorporate them into the classroom, is still more visible in the literature and practice than developing a manner by which to assess these skills. For example, although standardized assessments such as the OECD's Program for International Student Assessment (PISA) have incorporated cognitive competencies such as problem-solving into their testing, a manner to measure and evaluate interpersonal skills, especially in school settings, is difficult to achieve beyond looking at written and oral communication (J. W. Pellegrino, 2017). This presents a similar problem when seeking to identify these skills within data generated from educational settings.

In order to identify these skills within spoken or multimodal data, it is important to operationalize these more abstract concepts into concrete indicators and definitions (Bryman, 2012). With concrete indicators, it is possible to trace turns of talk and interactions among STEM participants and their environments in relation to these indicators, which makes it is possible to frame an ENA analysis on coded epistemics related to the 4C's.

In light of the inductive nature of this research project, the coding system in place is quite open and left to be derived, for the most part, from what is found within the data. Although the frameworks and indicators developed initially help to structure the investigation and coding of the data, it does not necessarily imply that they are present in the data. The ENA analysis is aimed to map what is present within the STEM activities and generate an understanding of the skills and epistemics unique to the cases, rather than structuring and conceptualizing them within rigid formulations based on existing literature alone.

Lastly, it is important to stress that all of the 4C's are examined together, and in relation to each other, rather than treated as separate constructs. It is a subtle but very important distinction within the ENA methodology when the focus of the analysis shifts from the constructs (often visualized as circles, called nodes, in a network) to the connections between the constructs (visualized as the lines, called edges, that connect the nodes). For example, when looking at an epistemic network that features separate nodes for communication, collaboration, critical thinking, and creativity, the focus is placed on the edges that connect these nodes and not the nodes themselves. This subtle distinction regarding the node placements provides further analytical meaning due to the node locations being determined by patterns of cooccurrence among all of the epistemics rather than some abstract location selected to showcase how each of the nodes are associated with one other node at any one time—to better understand interpreting network models refer to the Methodology section. This approach aligns with the underlying theoretical foundations of ENA when compared to the use of relational network theory, which focuses the analysis not on the presence of individual constructs, but rather on how they are associated with each other (Pachucki & Breiger, 2020). This allows for an understanding of the interconnected nature of the four soft skills, which is important for understanding learning according to the quantitative ethnographic perspective on learning as the connections formed among various epistemic codes within a discourse.

Unlike other research methods that can isolate one of these 21st century skills and attempt to provided explanatory evidence for the presence or influence of this one variable, ENA examines the 4C's in a relational method that seeks to understand the role of each soft skill over the course of the STEM activity in terms of how each soft skill cooccurs with the other three. What this implies is that explanations regarding 21st century skills within the context of this research study do not isolate any one of the skills but rather presents them within a network web of the other soft skill epistemics. Regardless of seeing all of the 4C's and intertwined, it is still vital to understand what each of the four 21st century skills are, how they are understood, and how they can be identified within the source data of this research.

3.6.1 Communication

Communication is more than just the surface details of how ideas are shared, and can be defined in various ways by various disciplines and perspectives. According to the P21 framework, communication is a multifaceted phenomenon that includes the articulation of ideas using various modes of communication (oral, written, or nonverbal), and the ability to listen and extract knowledge and meaning from what is communicated by others (P21 Partnership for 21st Century Learning, 2019; Partnership for 21st Century Skills, 2011). Communication, especially within the context of this research study, is seen as inherently interpersonal and is driven by goals such as demonstrating understanding and sharing ideas in order to achieve a particular outcome (Beesley et al., 2023). In order to build communication skills, taking on an experiential approach is valuable for learning these skills (Reith-Hall & Montgomery, 2022), which aligns with the use of this pedagogical approach within STEM activities that are aimed at encouraging 21st century skills development.

Within this study, communication is first derived from what people say, and the use of varied modes of communication that are present in their discourse. Communication is identified based on: 1) how the act represents an idea or knowledge construct that is meant to be shared with others; 2) how communicative acts help to create shared understanding; 3) how communication can contribute to shaping an empathetic and respectful environment; or 4) how such acts direct a goal related to the activity.

Some factors regarding communication that are specific to the STEM activity contexts of this research project are to explore both verbal and non-verbal communication among the STEM participants within their groups, and between the mentors and their mentees. Because group work is considered to be an important factor in building communication skills (Lawlor et al., 2014), looking to see how the STEM participants communicate in their groups as regards their engagement and the types of verbal contributions they make (e.g., questions, references to comments made by others, sharing ideas, showing empathy to the ideas of others, etc.) will be the first step. The second step is to do the same sort of evaluation of the mentors and to see how much of their communication is based on helping the participants with specific problems or merely overseeing the activity.

Additionally, within the ENA webtool turns of talk are coded based on connections made between topics of discussion and how participants draw on conversations to contribute further information. This is done using what is referred to as a moving stanza window, which codes turns of talk based on conceptual links that stretch over connections in discourse that transcend chronological utterances. The moving stanza window is set to finding links amongst every four turns of talk—see more about the moving stanza window in the Methodology section.

3.6.2 Collaboration

Collaboration is linked to communication within the P21 framework based on learner-to-learner involvement and the use of communication to drive collaboration (Kousloglou et al., 2023). However, to distinguish the operationalization of this construct from the definition above, collaboration is interpreted based on the ideas stemming from collaborative learning specifically, and focuses on how groups work together to accomplish tasks placed before them. Exploring how STEM participants divide up their responsibilities, and how they combine efforts to solve problems, are key to assessing collaboration, especially within a Problem-Based Learning context such as the STEM activity cases examined here (Anggriani et al., 2022).

Research into collaboration within educational settings is often based on perceptions of how well students worked together based on self-reported or peer assessment evidence (Le et al., 2018). However, this research attempts to derive information about collaboration from conversations and observations gleaned from the audio-video data. This verbal and non-verbal information features: 1) the roles that students and mentors undertake, and 2) how these roles reflect a division of labor that is meant to achieve the goals of the STEM activity. However, role assignment is only one aspect of how collaboration can manifest because how these roles work in isolation and how they work together to accomplish the overarching goal of the activity is important to consider to understand the STEM activity as a collaborative context.

3.6.3 Creativity

Creativity is a complex and multifaceted phenomenon that can be difficult to study when only viewing it from a limited framework. According to P21, creativity involves creating new ideas or improving upon efforts based on evaluations of ideas stemming from both individual and group settings (P21 Partnership for 21st Century Learning, 2019; Partnership for 21st Century Skills, 2011). In addition to the P21 definition, another way to explore creativity is to identify strands from the 4-Ps model (Rhodes, 1961) put forward some time ago and yet still used in contemporary work on creativity. The 4-Ps model identifies person, process, product, and press as strands of creativity and help to generate specific questions about how to identify and investigate this complex social and psychological phenomenon (Guo & Woulfin, 2016).

For this research project, only the concepts of process and product are considered feasible for investigating manifestations of creativity within the video-based source data. Process is understood as identifying how individuals come to novel solutions to problems when others seem to maintain conventional solutions. Product is a tangible artifact that reflects the outcome of a creative process and represents some degree of newness and originality. What these two factors for investigating creativity suggest for this research project is that epistemics within the source data look to uncover: 1) moments of insight or thinking outside of the box, and 2) interpreting the sorts of artifacts that are generated within the STEM activity. This means that exploring how the STEM participants work together to develop and fabricate an artifact can be witnessed and coded into epistemics.

In combination with seeking to identify coded epistemics for creativity linked to process and product, a questionnaire based on the popular psychometric Torrance Tests of Creative Thinking (TTCT) (Torrance, 1974) was also distributed to the participants of the teacher workshop case in order to triangulate video-based evidence of creativity with participant self-reports of creative thinking. Because psychometrics on creativity are fraught with criticisms about their lack of predicative, discriminant, and construct validity it is important to be cautious on relying solely on such methods in creativity research (Plucker & Makel, 2010).

3.6.4 Critical Thinking

Although critical thinking demands an investigation of its own based on the complexity of how to research and conceptualize it, for the sake of this research project critical thinking is relegated to a simple manifestation of process skills such as systems thinking (P21 Partnership for 21st Century Learning, 2019; Partnership for 21st Century Skills, 2011). Many of the current ways to identify and assess critical thinking and other process skills include the use of graphs and equations to solve science- and math-based problems or manipulating representational forms (e.g., chemical structures). These assessments of critical thinking are not typically designed for STEM educational activities, and formative feedback used in inquiry and collaborative processes (Reynders et al., 2020). For this reason, it is important to identify how subject-specific understanding of critical thinking can be extrapolated to be reliably applicable within STEM educational research.

Within the scope of this research, critical thinking is identified by how students evaluate claims or information to determine their level of agreement or understanding, and how students critically solve problems or create strategies for finding solutions that are not initially apparent or that require greater efficacy (Lamb et al., 2017). This understanding of critical thinking guides the investigation of the source data to pinpoint: 1) when students reflect or monitor their evaluation processes when faced with a challenge or with questions that they are not immediately able to answer, and 2) how students apply and interpret relevant information when refining solutions or troubleshooting problematic outcomes.

3.7 Methods for Researching STEM Learning

Although the importance of STEM education and the incorporation of learning activities that promote interest and knowledge of STEM fields have been a growing topic of educational research, questions still arise about how well this research can be practically applied to reliably establish the outcomes that are purported to be the hallmarks of STEM learning itself. That is to say, the body of literature that lauds the importance of STEM education can be dissected into 1) the validations of the curriculum for the sake of long-term outcomes within macroeconomic terms and 2) a micro-level understanding of if and how learning takes place within these activities, and what pedagogical aspects in their design may be attributed to learning and skills acquisition. It is possible to still champion the former outcomes of STEM education while remaining critical and open to fully investigating if learning outcomes and knowledge development align with the assumptions that lay at the foundations of how STEM learning is planned and deployed. However, if there are issues with how learning in STEM is evaluated and understood, it is possible that this gap could undermine the larger, social and economic, goals that underpin the STEM pipeline analogy and mission. This research does not engage with the first, larger, goal of STEM education, but it does investigate the second.

Published research into STEM learning holds up better to academic and societal scrutiny when more than just general claims about positive or improved learning outcomes are determined. Contextualizing these outcomes with pedagogical designs or learning processes that are evidentiarily present within the STEM learning environment provides for more meaningful and deeper understanding of both specific and general STEM education. In order to accomplish this detailed contextualization, data that can capture the act of, or the conditions that contribute to, learning are needed.

The ability for research to empirically identify and collect this information is demonstrated within the body of academic work within the data-driven field of learning analytics (LA). However, although LA research and practice are successful in collecting and representing learning data, the field acknowledges a failure with "closing the loop" in the research cycle to meaningfully translate these representations of learning data into understanding, and as a result generating improved learning and better informed teaching and learning strategies (Johnson et al., 2024).

The research project discussed here aims to address concerns about meaningful STEM education research by applying recently developed LA methods that can contextually represent and understand the learning complexity demonstrated within three STEM activity case studies. The purpose of this strategy is to identify a stronger connection with what takes place in the STEM cases and how these occurrences can inform an evaluation of effective implementation of STEM learning strategies. Simply put, it is easier to report if learning took place as the result of participating in a STEM educational activity, but it is much harder to determine specifically how learning took place in these contexts. This study does not seek to fully answer the 'how' of learning, but rather to contextually identify what is taking place in the STEM activity cases and to associate documented conversations and interactions with conditions conducive to learning.

This section on how STEM learning is researched explores some of the foundational presuppositions about 'what works' in STEM learning environments as presented in the body of academic work into STEM learning activities. The academic literature presented here primarily focuses on establishing methodological validity and rigor, and attributes substantive causal associations of positive learning outcomes with elements of a learning environment based on theoretical assumptions rather than direct evidential ties between what takes place in the environment and these outcomes (Cartwright, 2019). This lack of direct evidence to associate leaning outcomes with the learning environment is what creates an opportunity to investigate what takes place over the course of a STEM activity to better uphold any possible claims for learning having occurred.

Also, this section will take a closer look at particular methods that are used when coming to conclusions about the positive outcomes of STEM learning activities. The literature is divided into three main categories. The first is grouped by pre-test/post-test methods that take on a more intervention/semi-experimental approach to evaluating the outcomes of STEM activities and curricula. The second category encompasses studies that use various methods that rely on self-reported evidence to determine STEM learning and effectiveness. The third and last category will attempt to identify studies that apply more novel approaches that deviate from the former two traditional strategies in researching learning in general and STEM learning in particular.

All three of these categories are streamlined by focusing on literature targeting the development of STEM subject knowledge and 21st century skills, and which do so using STEM activities specifically. This brief overview of the most relevant literature is limited to peer-reviewed journal articles or conference papers published within the most recent years (2022-2024). This overview of recently published work on STEM activity effectiveness is not meant to be an exhaustive presentation of this body of work. Rather, this presentation establishes a practice within academic research into STEM activity effectiveness, and their impacts on learning, that do not always close the loop between their findings and more interpretive investigations of contextual information that contributed to these findings.

Reviewing these three categories of STEM teaching and learning literature aims to better identify where possible gaps in understanding how the particularities taking place during STEM activities (not just in theory or upon reflection) can be linked to the learning of integrated subject knowledge and 21st century skills. Furthermore, it is anticipated that gaps in the literature can motivate the use of more novel approaches to understanding STEM learning using relatively new and modern data-driven methods and techniques within learning research. This review also serves to inspire and validate the deviation from intervention and self-report methods that this project has taken over the course of several data collection iterations. The specifics of these methods are discussed in the following section on Methodology.

As a final note, the critiques below, which highlight the limitations of various educational research methods for bridging learning processes with learning outcomes, do not suggest that any of the mentioned literature is not without merit. In fact, the literature is presented well within the limits that such methods place on what claims can be made about STEM activity effectiveness. The following critique places the selected literature within a scope of inquiry that is outside of their intended aims, and so does not dimmish the value or contributions of these papers within the field of research on STEM education using STEM activities. Therefore, the critiques levied against the literature is presented in a critical manner that is intended to highlight the limitations of research that cannot document or capture the nuance of learning processes to enrich the analysis or interpretation of STEM activity effectiveness with respect to their learning outcomes, and does not make claims about the quality of the research presented in the papers.

3.7.1 Pre-Test/Post-Test Designs for Evaluating STEM

It is not surprising that a good deal of literature into the assessment of educational outcomes apply intervention-based research methods that reflect the typical summative assessment used to measure learning in school settings (Coe et al., 2021). STEM education, as it is often deployed in an educational setting, is also studied using these methods to determine if participation in a STEM educational activity or curriculum yields improved outcomes when compared to some previously established baseline derived from a non-STEM, or non-STEM activity, environment.

There is a good deal of solid literature presenting compelling evidence for improved STEM learning outcomes that utilize interventions that are purposefully and thoughtfully grounded in recognized learning theories (Hu et al., 2024; Komaria et al., 2024; Pekbay & Kahraman, 2023; Sari & Wilujeng, 2024; Sricharoen, 2023; Yildiz & Ecevit, 2022). However, these same research papers stop short of providing evidence from within the learning context itself to further prop up these findings and contextualize their meaning in relation to the processes of learning that may have taken place over the course of the activity. Understandably, this is not the aim of these studies, but this does limit their practical application to adoptions that directly mimic the details of the interventions, instead of attempting to put in place conditions to recreate the practices of how the participants enacted these activities.

Within the educational domain of pre-test and post-test methods are some research papers that focus on the practical implementation of a STEM activity, and report positive outcomes based on unfounded observations or allegorical evidence of how pleased or motivated the teachers or participants were (see Günsen & Çolak, 2024). Another example of how practical findings are presented without the use of tangible evidence from within the learning context, are papers that trumpet the potentially varied applications that a practitioner can select based on how the activity is adapted to various learning goals. Again, these studies present how such activities will theoretically yield positive learning outcomes based on the assumption of how particular learning strategies within the activity inherently contribute, regardless of potential confounding factors that could manifest in an environment to complicate the learning process (see Avcu & Eroglu, 2023).

In these papers in particular, it becomes plainly obvious how assumptions about what learning conditions are present in a STEM activity context can become *ipso facto* the evidence for why the STEM activity is interpreted as successful in promoting general STEM learning goals. However, this body of work is meant to target teachers and other practitioners and so the focus on the practicalities of STEM activities is prioritized over rigorous research analysis and evidence-based findings. However, this does motivate the need for more academic work into STEM learning activities that can apply an intervention research strategy that explores learning beyond the use of basic metrics.

3.7.2 Self-Report Designs for Evaluating STEM

Another research method that is often represented in social science research is the use of self-report data collection strategies such as interviews, open-ended questionnaires, or even Likert-scale survey instruments (Coe et al., 2021). Regardless of the instrument applied to collect self-report data, the validity of this information to reflect cognitive constructs, and the reliability of how this data can be used to accurately predict or explain human behavioral or cognitive phenomena is heavily criticized (Leeds, 2020). As a result, it stands to reason that research into STEM effectiveness that relies on self-report data should be considered carefully if the findings are extrapolated from individual opinions and used as evidence of more objective claims about a STEM learning environment.

However, it is possible to argue that this critique is situated within a perspective that seeks more objective facts and undervalues the importance of self-report data in generating subjective findings more attune to research about personal experiences and the opinions of participants. This particular research project into three STEM cases is not concerned with the subjective opinions of the participants, and so the use of self-report is only applicable if another source of data can be used to triangulate and confirm findings derived from participant claims and applied to understanding the STEM cases.

When looking into the literature evaluating STEM activities using either Likert-scale questionnaires or interviews, it becomes apparent that the lack of data from within the STEM context creates a gap in bridging subjective findings with the specific STEM activity, and with STEM learning theories in general. This results in academic papers that produce findings that cannot be verified. Specifically, findings are interpreted as disassociated from the specific learning conditions of the STEM activity and instead rely on general claims about what could be inferred as being influential based on general STEM learning processes (see Kizilay et al., 2024; and Ozdinc & Ceyhan, 2024).

Evaluations of STEM activities that go beyond the scope of what subjective data can yield, run the risk of producing claims that merely beg the question about contextual processes within the learning context. What results is a subtle logical fallacy that presents a STEM activity as an inherently effective learning strategy due to it being interpreted as both the cause of learning and as a broad explanation for how learning took place. This fallacy can be avoided by associating STEM activity learning outcomes to contextual processes that reflect the pedagogical framework of a STEM activity's design instead.

3.7.3 Combining Semi-Experimental and Self-Report Designs

It is not uncommon for educational research to apply mixed-methods approaches that combine the use of quantitative intervention data and qualitative self-report data (Coe et al., 2021). Although mixed-methods research (MMR) can provide a way to triangulate findings and offer thicker descriptions of learning data, such research strategies can be time-consuming and deemed unnecessary depending on the aims of the research inquiry itself. Also, the use of MMR strategies does not immediately result in an analysis of STEM activities that addresses possible concerns that could be addressed using only quantitative and qualitative methods, or an analysis that closes the analytical loop of inquiry.

When conducting a brief search of the academic literature applying MMR strategies for determining the effectiveness of STEM activities, it is possible to find research of good quality that produce compelling and useful results, but that do not attribute the results back to specific tasks or student's work (Fernández et al., 2024; Karamustafaoglu & Pektas, 2023; Meral et al., 2024). These articles make good use of the MMR design, but focus on triangulating the data findings rather than uncovering learning processes. As in the examples of other methods, the limitation is a lack of information about what is taking place in the activity, which may assist in coming to conclusions that associate the findings with more than just the STEM activity itself.

3.7.4 How Novel Research Methods can 'Close the Loop'

The use of traditional research designs using interventions, self-report, or a combination of the two methods are well-established and valuable avenues for gathering information about the effectiveness of STEM activities. However, a critical eye can detect a disconnection between how STEM activities are understood, with respect to enacted learning processes based on pedagogical design, and the outcomes of research into STEM learning. This can be attributed, among other things, to the limitations in data collection strategies that fail to capture evidence of the systematic events that take place within the activity, and how this evidence can be used to deepen an understanding of the conditions for learning present within a STEM educational context. However, although the traditional research designs outlined earlier are well-established practice, they are not static nor are they subject to strict traditional application.

Developments in research methodology are ongoing within various academic disciplines. Within the domain of educational research, this development or adaptation of established or traditional methods can be due to many factors, including the inclusion of previously underrepresented perspectives (Swartz et al., 2024) or modern technological developments in data collection and analysis (Lin et al., 2024).

Within the most recent literature on STEM activities, it is possible to see strategies that understand the need to derive more applicable and practical findings that demand a better investigation of learning processes within STEM activities. What is important to note is that research into STEM effectiveness and research into understanding learning and the implementation of STEM within the context of pedagogical learning theories are not yet fully aligned within the literature. However, similar to the stance taken within the presentation of this research project, there is a growing recognition that research on STEM focuses more on the findings rather than the methodological issues of how these findings are intended to link practical outcomes with theoretical claims about STEM educational effectiveness (White et al., 2020).

The implication is that a disconnection between how a theoretical framework for STEM learning, that is described within a research project's theoretical outline, can be overlooked within a presentation of research findings in terms of explanatory variables to the overall trends in the learning outcomes. However, in order to engage with research findings that can loop back to the established STEM framework requires newer methods of collecting and interpreting learning data that can capture the occurrences that take place over the course of an activity. It is this approach that has been one factor in the importance placed on methodology in this presentation of the three STEM cases.

There are examples of promising STEM literature that are able to move away from the focus on findings; however, as indicated earlier these sorts of research papers tend to address more practical issues within STEM learning and implementation. For example, (Lin, 2021) moves away from testing and self-report data and focus on following the stages of implementation of a STEM activity for the purpose of generating a more flexible practical application of the activity outside of the cases examined within the scope of the particular study. It may be a promising approach to moving the STEM learning literature forward by better establishing the link between theory and practice within discussions about findings regarding STEM effectiveness, and which can be a possible avenue for closing the STEM learning analytical loop.

In conclusion, whenever research on STEM is conducted, an established framework for how to conceptualize the sorts of learning strategies that are designed to be utilized and enacted by the learners—or even by the instructors—is needed in order to understand the pedagogical topics being investigated. However, this framework can also be an instrument to guide methodological issues on how to collect learning data within a STEM context, and as an investigative framework for how to link the findings of the study with specific enacted activities within the STEM context.

The argument presented here is that if exploratory research into STEM activities addresses the methodological implications for closing the analytical loop for contextualizing the learning opportunities provided within STEM activities, it is possible that the practical implementation of such activities can be designed for effective results within other learning contexts. Regardless of what approach is taken, the importance placed on systematically characterizing the anatomy of a STEM activity is applicable for not only defining what STEM activity learning is intended to be (Hussim et al., 2024), but for also framing a deeper discussion about how conditions for learning may have occurred to underpin the learning outcomes identified within an analysis.

3.8 STEM and Engineering Student Mentors

The learning strategies present within a STEM activity can also take into account the composition of the participants within the activity and how individuals can become factors in learning similar to how learning is understood within a *community or practice* (Lave & Wenger, 1991). Learning strategies in STEM education, like in other learning environments, cannot be isolated from the teaching contributions within the context. By deliberately incorporating participants with specific knowledge or qualities into a learning context or group, it is possible to account for these participants as factors in the learning context. Unlike the traditional classroom role of a teacher, the teaching contribution within the three STEM activity cases examined here apply a construct more indicative of the *Teaching Presence* construct defined within the Community of Inquiry framework (Cleveland-Innes et al., 2024). The teaching construct within the three cases is defined as a ‘mentor’ that provides feedback, instruction, knowledge, guidance, conflict resolution, and other contributions to help the participants succeed in the activity as a group.

The use of mentors within STEM careers and STEM education at the tertiary level is a well-regarded practice in light of its ability to prepare students for STEM careers (Hyams-Ssekasi & Caldwell, 2019; Kaul et al., 2015; McAlpine & Pleschová, 2015; Schofield, 2019). One STEM case study looked at the use of 'making' within engineering education with real-project-based learning approaches in collaboration with industry mentors as a successful strategy for developing the desirable attributes of a global engineer and the 21st century skills philosophy (Juarez-Ramirez, Jimenez, Huertas, & Navarro, 2017). Although the use of mentors or mentoring practice is not necessarily an overt aspect of all STEM educational activities or environments, and is not included in the formal STEM education framework, the cases explored within this research project feature the use of mentors as a valuable contribution within those particular contexts and cases.

The rationale for the use of mentors was driven by the experiences of the founders of the non-profit during their higher education studies and recognizing the mentoring practice as a part of preparing STEM students for later STEM careers (especially in the fields of computer science and engineering). Furthermore, the belief of the staff was that higher education STEM students could benefit from serving as mentors within the STEM activities as it would allow them opportunities to develop their own 21st century skills. Mentors are a source of knowledge and expertise, but they also learn and improve their own skills too. Arguably, all participants within a learning context can be conceptualized as both learners and teachers to some extent. In order to develop findings on the cases presented in this study, it is essential to determine what mentoring means within STEM, and to also determine how it aligns with the overall ethos of STEM education beyond just the personal attitudes of the non-profit organizers that plan and develop their specific STEM activities.

The mentors that take part in the STEM activities investigated in this research project all come from computer, electrical, or mechanical engineering backgrounds. Also, many come from outside of Sweden and do not speak Swedish (despite the STEM participants being Swedish) and so reply on the use of English as a mode of communication. In light of the educational backgrounds of the mentors, it is important to address the manner by which the STEM activities that these mentors take part in are also designed to improve on the skills gap between technical and professional skills among engineering graduates.

With respect to engineering education, which is one of the key focus areas of STEM careers, there is a recognized need to promote human social performance and professional soft skills. This shift in focus from the current model, which focuses on technical expertise and knowledge, to one that also works to foster or improve social and professional skillsets, targets the needs of modern industry and employer demands (Trevelyan, 2010). As engineering curricula strive to accommodate the bridge between knowledge and workplace competencies, there is a stronger push in recognizing the importance of modern 'new engineers' with both soft skills and technical knowledge. Creativity and innovation, as well as general social skills, are important for engineering (Badran, 2007), as well as for other technical fields like digital technology, which are driven by the evolution of ideas and products. By allowing engineering students to mentor less advanced STEM learners, the non-profit that organized the STEM activities examined in this research project intended to help build the social and professional skills of the engineering student participants.

This research project aims to determine what the role of mentoring contributes to the overall epistemic frame of the STEM cases explored in order to determine the value of this practice for the mentees and the mentors from two perspectives: 1) in the case of the mentees, how do the mentors help them during the activity; and 2) in the case of the mentors, how does serving as a mentor help improve their own 21st century skills practice and development.

4. Methodology

A detailed overview of research procedures provides a standardized determination of research quality, while also explicating the theoretical positions that frame the approach within an acceptable scientific paradigm. The quality of any research is founded on utilizing appropriate perspectives and instruments that provide reliable and robust findings that can contribute to the pursuit or construction of knowledge within a discipline. Research design is therefore intrinsically linked to how meaningful the results can be, and in determining if the methods and methodology applied are appropriate to systematically derive these results.

Methods

This chapter details the use of Quantitative Ethnography (QE) and Epistemic Network Analysis (ENA) to investigate a selection of STEM activities to identify networks of cooccurrences between knowledge and skills and how these patterns may inform theories of STEM learning such as experiential learning, problem-based learning (PBL), and collaborative learning. This research builds on a growing body of academic literature about investigating collaborative and problem-based learning processes using advanced ENA methods that improve upon both indicator- and connection-centered analysis (Ba et al., 2024).

The QE analysis produces network models for each of the three cases, and these networks visualize the connections between STEM knowledge and 21st century skills while also isolating the specific data utterances that are associated with these connections. This results in an investigation into the cases using both statistical tests of the network metrics, and the qualitatively abductive interpretation of the information that generated these relational parameters of the network model.

This use of both quantitative and qualitative methods aims to deepen the contextual understanding of the cases by “closing the analytical loop” and attributing more meaning to potential learning processes derived from the analysis. The aim of this approach is not to contribute another reductionist validation that STEM education improves academic outcomes, because this study does not seek to measure what the participants *learned* within the activities. Rather, this project aims to elaborate on what *conditions for learning* are present within the cases to determine if these conditions support or refute the theoretical assumptions regarding why STEM education produces favorable learning outcomes. Using observational methods to document how participants use knowledge and skills, rather than attempting to extrapolate their acquisition, aims to address the aforementioned gap in other research into STEM activity effectiveness that does not capture how knowledge and skills manifest from and among STEM activity participants.

This study primarily collected audiovisual data for analyzing the interactions and communications that takes place within the cases. This was done based on the laudable qualities of audiovisual data in providing a temporally sequential and multimodal record of utterances and interactions that can be observed more than once and therefore applied to various levels of analysis. The particular analytical methods outlined in the upcoming discussion motivate how audiovisual data of multimodal interactions can be transformed into evidence and contribute to a better understanding of how learning theories underpin STEM activity contexts.

Audiovisual data is not the most common type of data used for ENA and does present some challenges for its applicability to the method. However, audiovisual data is amiable to ENA and QE as regards the abductive closing of the analytical loop by the very nature of the data being available in its raw form upon subsequent observations. Furthermore, the coding of audiovisual data can be conducted in a manner that transforms this raw information to a format conducive to using computational analysis such as ENA.

Theory

The claim that this research aims to generate interpretative meaning from objective network models belies a logical contradiction in the foundational theoretical perspectives of both qualitative and quantitative research designs. This chapter addresses the implicit ontological and epistemological claims justifying the use of a model-based analysis in addition to outlining the methodological approach of conducting a case study design with an abductive stance on the relationship between existing learning theories about STEM activities and the sort of data that this study utilizes.

The potential conflict with the conflation of mathematical models and ethnographic interpretation within a cohesive analytical perspective on what STEM learning is and how it can be understood is assuaged by the importance that quantitative ethnography places on "closing the analytical loop". This approach reestablishes the meaning behind quantitative findings by embedding them back within the interactional source data. This allows for the generation of contextual and interpretive thick descriptions that contribute to the trustworthiness of the results and increased confidence in the practical implications they support.

What results is an approach that can utilize a realist ontology with an objectivist epistemology that is tempered by—but not necessarily based on—the addition of interpretive complexity for understanding learning as a social phenomenon that is reflective of individual contributions to shaping the STEM activity over time and its final aggregate structure. These contributions, in the form of verbal or nonverbal interactions, may reflect the individual subjectivities of each participant as embedded within the conscious or subconscious influences of abstract systemic constraints, but the practice of closing the analytical loop in QE methodology does not necessarily require contributing causal or explanatory meaning at this analytical level.

For example, after ENA isolates significant relationships between skills and knowledge or significant differences between one or more participants within or between the various STEM activity cases, it is possible to subject the utterances these findings are based on to a deeper level of analysis to explain to a reasonable degree why these utterances contribute or shape the findings. In the case of this specific research project, and because the scope of the questions and aims exclude evaluations of learning outcomes or the experiences of the learners *per se*, it is possible to conduct a level of interpretative analysis that focuses on the structural aspects of the STEM cases as an external reality generated by the participants interactions and utterances and not as a fluid entity that is understood and provided meaning based on each participants subjective experiences and interpretations. That is not to say these cases cannot be examined through the lens of critical or relativist theories of learning, because the inclusion of these perspectives would generate meaningful insights that delve even deeper into understanding the role of each individual participant in shaping the STEM activity in a manner that aligns with the foundational ideologies that shape QE methodology.

However, when seeking to understand the conditions for learning present in these three STEM activity cases, the interpretative gaze is situated on what occurred (verbally or nonverbally) between the participants over the course of the entire activity to generate the learning environment that is represented by the network model. This analytical focus does not require explicating sociological influences (e.g., gender, race, culture, power, stratification, etc.) as causal or explanatory variables in shaping the very communications and interactions that are used in the construction of these network models. This suggests that closing the analytical loop in the manner of how it is applied in this QE study does not mean having to apply subjective epistemological perspectives. The meaning generated by closing the analytical loop in this study is applied to better understand how the things that were said and done can be reflective of learning conditions in order to explicate how learning is shaped by the participants within their constrained and situated group dynamic.

4.1 Ontological and Epistemological Premises

The use of Quantitative Ethnography suggests the use of mixed methods research (MMR) approaches combining quantitative and qualitative methods, which are considered paradigmatically irreconcilable and as a result symbolic of conflicting ontological and epistemological foundations. However, such traditional perspectives on scientific knowledge and research are shown to be lacking in flexibility when accounting for investigations that can be positioned within either or both ontological camps and still apply the use of several epistemological methods to understand a phenomenon from various perspectives, or in a more iterative or dialectical manner (Ghiara, 2020).

Although more common within the social sciences, the use of MMR is also finding value within the hard sciences. This is most notable in scientific fields (e.g., environmental sciences and engineering) that produce research meant to have practical implications, and which benefit from MMR that apply interpretive perspectives to improve existing scientific models or adapt these models with greater contextualization (Salgado et al., 2024). The investigation of the three STEM activities that are the subject of this research project is also suited to MMR based on wanting to identify structures within the activities, and to apply a deeper interpretation and understanding about what specific interactions contributed to the structural interpretation of the three cases.

This research project is primarily tasked with translating audiovisual data of learners participating in experiential, collaborative, and problem-based STEM activities into network models representing subject knowledge and modern 21st century skills as displayed by the interactions between the participants and their environment. This research is premised on the belief that the audiovisual data can be used to access constructs related to subject knowledge and 21st century skills, and that the resulting networked visual model interpretations can be used to evaluate existing claims about STEM activity learning frameworks.

This focus on network analysis, and how this can inform further qualitative investigations into the structure of the STEM activity network models, brings into focus the need to clarify the very nature of the networks and how knowledge about them can be attained (Pachucki & Breiger, 2020). The very notion of examining the ontological and epistemological foundations of networks goes beyond a mere model-based theory of understanding complex social contexts such as the STEM cases examined here (Pachucki & Breiger, 2020). Moving beyond a model-based theory of understanding networks should not be taken as a blanketed critique of the very practice of using network models as a basis for understanding social relations. Despite this valid critique, the appropriateness of using a model-based theory is valid for the aims of this investigation due to the focus of academic inquiry targeting the anatomization of the STEM activities as case-specific entities.

The anatomization of the cases within network models requires translating raw audiovisual data into a format that can represent observational evidence of specific epistemics representative of this activity. The claim that observations of activity can yield interactional data that can further be codified to represent knowledge constructs and skills-based practice is founded on an empirical mindset rather than an interpretive one. Furthermore, the very nature of construct representation is two-fold when attempting to observe and codify phenomena as complex as abstract cognitive skills like critical thinking and creativity, or more performative physical constructs such as communication and collaboration.

From an ontological perspective, this research is situated within a social realist perspective on how to construct a visualization of STEM activity framed by specified units of analysis identified within the raw data. For example, this research is driven by investigating the STEM cases in how they structurally deviate or coincide with what is theoretically prototypical of a STEM educational context that is designed to be pedagogically conducive to learning subject-based knowledge and encouraging the development of interpersonal and noncognitive soft skills.

In pursuit of this aim, this research project is primarily interested in the anatomization of the STEM activity cases rather than possible socioemotional experiences of the activity participants or the macrosystemic value of STEM within the overall STEM pipeline or socioeconomic global stage. This further directs the research away from other valid and interesting perspectives on collaborative learning environments by focusing more on relational networks between units of analysis rather than any potentially hidden complex hierarchical or other socially constructed variables that may underpin the networks and the epistemic frames generated by the analysis. The implications of this perspective align with the ontological foundation that the networks analyzed are not subjective constructs to each of the social actors, but rather reflect a structure of the STEM activity itself as situated within the epistemic frame generated by audiovisual data of activity and communication within the cases.

When considering the epistemological premise validating the use of coded units of analysis derived from the audiovisual data, this research follows a post-positivist perspective on understanding and interpreting social reality and phenomena. In accordance with an epistemological strategy of this nature, the networks generated in this research can be analyzed using quantitative values to give meaning to the relation between the various units of analysis within the network regardless of whether or not the unit of analysis is a social actor or an abstract epistemic. However, it is not simply the use of statistical methods that positions this work within a positivist camp. The use of ENA does not immediately imply a belief in strict and objective empiricism on the part of the investigator because the ENA method can be used to address interpretive inquiries into socially constructed roles, power dynamics, and knowledge production within epistemic networks (Q. Liu & Luo, 2024).

The use of the ENA method and the focus on generating and interpreting network models is adaptable to either objective or subjective epistemologies without having to compromise the ontological worldview from which the methodological framework originates. This is also witnessed in how sociological understanding of the relational structures of social networks differ based on epistemological rather than ontological assumptions, and which can benefit from the use of mixed-methods approaches that can identify objective network structures without having to attribute meaning of that structure as based on only one specific cultural-historical set of circumstances or influences (Singh, 2019).

The purpose of identifying the STEM activity models for the cases examined here is to evaluate claims made about STEM learning in somewhat relatable contexts. This requires a perspective that the knowledge generated about structures between subject knowledge and 21st century skills practice reflect patterns of STEM learning dynamics that can be understood without the added layer of personal or interpersonal variables on the part of the participants. Although this is an interesting perspective, it is not the focus of the investigation undertaken here. However, these perspectives that target the most basic and inherent characteristics of STEM learning, and which do adopt a more objective perspective of what these models represent, do not disqualify interpretative complexity within the analytical process *per se*. Rather, the very use of an interpretative framework to understand specific patterns in the network data is applied to interpreting the presence and development of instances that reflect conditions for learning that could be used to underpin the connection between 21st century skills and STEM subject knowledge epistemics within the verbal and nonverbal communications of the participants. Instead of focusing on sociological influences behind the anatomical network structures of the STEM cases, this investigation seeks influences exerted by the participants that reflect data-based actions and words used to accomplish the STEM activity task, and how these influences shape and generate meaning about learning within such cases.

4.2 Interpretive Framework: Quantitative Ethnography as Methodology

Although a greater deal of attention is paid to the use of Epistemic Network Analysis (ENA) as an analytical method for interpreting and visualizing the results of this study, it is still important to ground this method within its overarching methodological ideology of Quantitative Ethnography (QE). One of the issues with the use of ENA purely as a method, is that it can be applied to inquiry that does not have to be founded on QE theories about learning—which may be considered a strength depending on the opinions of individual researchers. This research project grounds ENA within the QE framework in order to close the analytical loop in an effort to better understand what conditions for learning may be present within the selected STEM activity cases examined.

As the name implies, QE combines the two seemingly contrasting methodological strategies of quantitative and qualitative social science research with a focus on statistical methods and ethnographic theories. However, this approach is in actuality meant to reflect a truly blended mixed-methods approach by allowing for the quantitative analysis of qualitative phenomena and data, instead of using the two approaches in 'separate tandem' concurrently or sequentially. The combined theoretical discussion of how QE research classifies and interprets ethnographic data (in both real-world and digital environments), and then later codifies and translates this into numerical data for analysis using ENA, rests at the heart of understanding this new methodology within the learning sciences and educational research.

From the perspectives guiding this research project, the audiovisual data used to document the verbal and nonverbal interactions taking place between participants in a STEM activity, and how the participants navigate the STEM activity context as a purposefully designed pedagogical environment, are well-suited to QE methodological principles and theoretical underpinnings. This is especially the case when considering how this source data can be validly and reliably codified in a manner that reflects knowledge constructs and skills enactments. Furthermore, the theoretical foundations of QE align with how the source data is interpreted to represent social and cognitive epistemics that exert influence on one another in shaping the social and cognitive environment in which they are situated.

The theoretical foundations of QE take inspiration from various cultural and cognitive disciplines including human action and interaction, linguistics and communication, ethnographic and cognitive anthropology, and influences from discourse analysis. Some of the key figures cited in the development of QE include: Edwin Hutchins and his influence on the development of distributed cognition in human-computer interaction; Charles Goodwin and his perspective on interactional linguistic anthropology and his view of discursive practices as displays of expertise within professions; and Clifford Geertz who formalized the use of thick description within his brand of ethnography as a manner of understanding culture that connects an interpretive analysis of observations to contextual meaning (Shaffer, 2017).

From a methodological point of view James Paul Gee's distinction between 'big-D' Discourse and 'little-d' discourse, Erving Goffman's subtle knife in data segmentation, and even the connection between Lave and Wenger's *communities of practice* as epistemic frames, are combined to reflect methods of coding and framing interactional data within a structure that can be interpreted by networks and spatial visualizations of related interactions (Shaffer, 2017).

Taken together, these theoretical foundations establish how social interactions and individual cognitive manifestations can be represented and understood within networked patterns. However, the networks generated by ENA reflect the more complex MMR theoretical foundations of QE and are distinct from the more numerically abstract networks found within more common network analysis methods.

The network plots that are interpreted within a QE framework are unlike those of social network analysis, and reflect more the analytical spaces/frames used in other established methods such as correspondence analysis (CA), which visualize and quantitatively interpret relational data (Pachucki & Breiger, 2020). However, the use of discourse and interaction data, in addition to the data being dynamic and taking place over a relatively short time, makes the use of CA incongruous to the aims of this research project due to how CA focuses on simple relations between variables and not the cooccurrences between these variables as seen in a structural relational network generated within QE and ENA approaches (Shaffer et al., 2016).

As stated earlier, the networks generated within ENA, and which are grounded on the principles of a QE framework, place greater importance on the relationships between the components of a network rather than the composition of the network itself. The relationships between the network components highlight the importance of discourse and interactions above the mere presence of any one network component, as would be found in network analyses not grounded in QE principles. Tracing and establishing interactional and discourse-based influences within a network model results in the need for an analytical space to interpretatively situate the network to bring to light the interactional influences and connections generated by the network components. This is referred to as the *epistemic frame* in ENA, and represents how QE theory interprets community of practice, or the thick big-D Discourse that is constructed by the interactions of the network components.

This epistemic frame allows for the network models to be understood using the theoretical foundation of QE rather than by using only basic network measures such as density, clustering coefficients, and various centrality metrics. However, the concept of epistemic frame is often defined in various ways that connect it to more than just a community of practice. The epistemic frame reflects a discourse and a professional culture in terms of the systematic connections between the ‘Codes of a Discourse’, where the Codes are distinct ways that a particular community/culture sees or acts within their context/world (Shaffer, 2017). The ethnographic aspects of QE are linked to observing and coding spoken or multimodal utterances and interactions within a particular setting, in order to arrive at a thick description of the culture of that particular setting as regards the interactions of what the utterances represent as cultural meaning.

Quantitative Ethnography attempts to move beyond simplified cultural observations and descriptions of what exists and takes place in a learning context, and moves toward emphasizing patterns of relations between what exists and is utilized within the cultural context of a group. This shift in intended to allow for quantitative tools to interpret the structure of the network culture from this relational perspective. This implies a shift from the units of analysis in ethnographic research being about what exists in the environment, to better understanding how they exist together in an overarching cultural frame. For this reason, QE is suited to social research into education and learning that is interested in understanding how various interactions take place, and how this relates to learning rather than simply identifying the factors present or not present within a learning context.

Learning, according to QE, is understood as the connections that are made between epistemics (i.e., knowledge constructs), and not merely in how they are present in the setting. Learning becomes a process of developing an epistemic frame comprising of patterns of association between cognitive elements, such as the skills and knowledge that are shared by a group or the environment shaped by professional practices such as in engineering or medicine (Shaffer, 2003). Developing and understanding this epistemic frame for the STEM activities explored in this research project is one way to understand how learning can be shaped within them—especially in terms of shaping conditions for learning. Therefore, using QE to identify STEM knowledge epistemics and how they are connected to 21st century skills can be accomplished by the methods and perspectives that underpin this newer approach to understanding learning.

Some of the problematic aspects of QE, with respect to the particular methods employed in this research project, are associated with the influence of computer-supported collaborative learning and automated processes for coding and segmenting utterances and stanzas within the spoken communications between event participants. Although these processes are vital for the feasibility of projects with large amounts of raw data, they do also compromise the nuance that can exist in complex group interactions and discussions. Automated processes are not used in this project, which resulted in a tradeoff between the sheer breadth of the raw data used to construct the epistemic frames, and the ability of smaller data selections in being able to capture more detailed nuances in participant interactions. This has resulted in more analytical decisions being taken in the selection of raw data segments to be included for transcription and inclusion in the analysis. For example, this results in the exclusion of unrelated utterances (e.g., personal conversations between participants unrelated to the activity) and the deliberate selection of key stages in the projects that are associated with systematic task accomplishment (e.g., brainstorming, planning, prototyping, etc.). This has implications for what generalized claims can be made about STEM learning as regards the limited epistemic frames generated in the analysis.

4.3 Pilot Studies and the Current Project Iteration

The current iteration of this project came about after various pilot study observations and data collection episodes. These pilot studies were conducted within several different STEM activities that were organized and delivered by the same non-profit that organized the three STEM activity cases eventually selected for investigation in this research project. As familiarity with the context of the three STEM activity cases later selected for targeted analysis evolved, it became increasingly obvious that traditional methods used to evaluate and assess learning within STEM activities needed a more systematic approach to be able to better account for the realities that take place during the activity itself. The main concern that was gleaned from patience and long-term investment in observations of various STEM activities prior to the delivery of the selected cases, was that traditional educational research methods such as intervention studies, pre- and post-test methods, and survey studies reliant on self-reported interview or questionnaire data all failed to capture the real-world evidence of what was taking place during the activities in a real-time context.

It became increasingly obvious that the key questions driving curiosity about how STEM education could achieve its macroeconomic and micro-level learning outcomes were based in better understanding and evaluating the finer details that take place over the course of the activities for each of its participants, and to map this data within a framework of learning theories that are meant to align with such activity and interaction. Very simply put, this research turned away from being driven by questions about *how* effective STEM education is by way of quantitative or qualitative evidence. Instead, questions about *why*, and at what points, STEM education promotes learning and knowledge development and how this could be uncovered using mixed-data evidence.

These more exploratory questions seek data and evidence that serve to both validate learning claims about STEM education while also identifying gaps between traditional measurements of learning, and the learning theories that are often inductively anticipated to be present in STEM educational outcomes. By exploring STEM learning, rather than testing its outcomes, it is possible to improve on how the particular activities designed and deployed by the non-profit investigated here can inform the replication or adoption of similar STEM activities in other contexts based on how they can be associated to the promotion of specific targeted learning outcomes (whether knowledge-based or skills-based). The use of traditional methods cannot necessarily allow for such as detailed and holistic evaluation, as demonstrated below with a discussion of previous attempts to research and capture learning data from past activities provided by the non-profit.

The first pilot study was conducted over the summer of 2018 and aimed to assess what subject knowledge was learned by the use of experiential learning practice and mentoring within a makerspace environment. The evaluation of learning took place using quizzes that were administered before and after the activity, and with the assessment of the artefacts designed and fabricated by the participants. However, because this data was also collected in combination with observational data, it quickly became apart that any conclusions drawn from the quiz data and artefact assessment was confounded by other factors that were not present within the narrow scope of the evidence that would have been the subject of the analysis—namely the before and after quiz results. Based on this experience, it was determined that in order to draw out more complex factors in STEM learning, and to better assess the outcomes of STEM (whether skills- or knowledge-based), required identifying research methods more suitable to looking at real-time data.

The second pilot study took place in the spring of 2019 and attempted to use a different method of collecting data on STEM activities in the form of self-reports on the outcome of STEM activity participation via interviews and questionnaires. This pilot study collected data from only the mentors participating in the activity due to ethical restrictions and concerns of feasibility—i.e., the participants were under the age of 18 and therefore were not able to consent to taking part in research. However, these ethical limitations were not of great concern because the focus of the pilot study was only on the mentors. This pilot study was meant to determine how participating in a STEM activity in the role of a mentor, helped to improve the 21st century skills of engineering students. This study also proved to indicate some concerns about data reliability as it became very evident that mentors were well aware of what sorts of responses would have been most advantageous to make, which resulted in a marked acquiescence bias. Furthermore, the role of this researcher within the landscape of the non-profit perhaps influenced the mentors to provide only positive feedback and claims about the impact of the activity. For this reason, it became apparent that working so closely with the non-profit would serve to limit the honesty of the mentors should the feedback be used by the non-profit for improvements to future STEM activities.

With these concerns in mind, it became apparent that a new approach was needed in order to ensure the objectivity of the data, and to offset any factors linked to the close proximity of the researcher to the non-profit—the researcher had been injected within the context of the non-profit for several years at this point and many participants may not have been able to distinguish the independence of the researcher from the non-profit employees. The study took a stark turn toward less traditional, and more complex, data collection strategies that would yield data that could be analyzed in a manner that was more deductive and objective. For the purpose of avoiding the pitfalls discovered from previous pilot studies and research, a methodological strategy was identified that could best address the concerns of authentic learning data and the type of data that could best delve into the micro-level aspects of learning within complex STEM activities.

4.4 The Data-Driven Approach to Educational Research

This research project takes on a data-driven approach to educational research in light of the availability and functionality of newer analytical tools and methods coming out of the data and computer sciences. Furthermore, a data-driven approach to scientific reasoning, especially when seeking to uncovering knowledge or patterns in digital information, turns away from strict adherence to theory-based deductions (Egger & Yu, 2022), and allows for more focus to be placed on the use of "pre-social" information generated from passive human-machine interactions (in this case, video cameras) that do not require rigid analytical frameworks or purely theory-based hypotheses that can limit data pattern exploration, understanding, and eventual analytical findings (Balazka & Rodighiero, 2020). This approach is well-suited to the exploratory nature of a study employing a QE interpretative framework, and is also well-suited to the sort of data being analyzed in this research project.

However, it is evident that the use of quantitative ethnography requires some degree of analytical decision-making, especially in decisions related to the coding of interactional data and utterances of both verbal and non-verbal natures (Shaffer, 2017). For this reason, the data-driven approach used here allows for some alleviation of the sorts of critiques levied against this approach by allowing a tempering of the importance of data by the expressed understanding that analytical interpretations are not entirely removed from the research and the knowledge-generation process. Furthermore, this project embraces the integrated mixed-methods available from quantitative ethnography (i.e., using quantitative methods to analyze qualitative data), which places importance on data-driven and inductive reasoning, but that still places emphasis on some level of theoretical understanding of the variables or units of analysis to make appropriate use of the method. It is not uncommon for educational research studies to combine data-driven approaches within learning analytics with a hypothesis-driven use of literature, or past experiences of researching the same phenomenon, in order to take advantage of both approaches to better understand an educational phenomenon from an exploratory point of view (Grover et al., 2017).

With growing trends in the generation and availability of big data within educational settings, and when using technology to mediate human learning and interaction, the use of data-driven approaches is becoming more common within social research and within the educational sciences. This can be seen with the use of data mining techniques to predict and take action on student performance (Gil et al., 2020; Liu et al., 2017; Marx et al., 2020; Qian & Lehman, 2020), the use of learning analytics generated from various sources such as learning management systems and technologically-mediated learning games and simulation platforms to improve learning output (Klerkx et al., 2017; Pardo et al., 2017), and for the use of such approaches in educational planning and decision-making (Backenköhler et al., 2018; Iyengar et al., 2015;

Little et al., 2019). Data-driven approaches are not uncommon in social science and educational research, and according to the OECD, "[t]he continued development of new technologies will advance acquisition, sensing and processing capabilities of data collection in real-time during learning and in real-world contexts" (Kuhl et al., 2019). This opens up opportunities to explore and observe learning taking place in real-time, and which can be analyzed using more data-driven theories, methodologies, analytical tools, and strategies.

This research project takes on a more data-driven approach to analysis in light of the focus on networks as interactional manifestations, but also in response to how theory and method can be aligned within a more abductive approach to knowledge development. This approach is not unprecedented and can be witnessed in other studies where the use of data-driven approaches to research on network information helps for patterns in the data to drive analysis and interpretation of findings rather than relying on the use of *a priori* hypotheses (Andersen et al., 2020; Park, 2020). Under the umbrella of data-driven approaches, this project embraces the perspectives and discussion on educational phenomenon stemming from the learning analytics and quantitative ethnography communities. These two specialties within educational science and research follow the use of data-driven approaches but also allow for more theoretical influences over the course of investigation of teaching and learning (Knight & Buckingham Shum, 2017).

Learning Analytics (LA) is one of the most important trends for technologically-enhanced learning and teaching within the combined fields of educational research, computer science, and statistics (Johnson et al., 2013). LA is defined as the measurement, collection, analysis, and reporting of data about learners and their learning contexts (Elias, 2011). Although the use of LA is common for investigating student interactions with, and via, digital platforms (Siemens and Long, 2011), the application of people-centric urban sensing (Campbell et al., 2006) can introduce LA to complex physical environments and experiential learning practices as well. However, the use of sensors and big data is not without controversy (Campbell et al., 2006). This study is situated within contemporary debates among the research community regarding data security and privacy, and the ethical issues related to the use of research participants as part of the sensing infrastructure. However, these ethical issues are addressed by anonymizing data and limiting the intrusive nature of data collection instruments by adopting more passive data collection strategies.

4.5 Case Study Design

The use of case study design is fitting for this study by the very nature of the phenomenon of STEM activity learning being linked to particular and limited contexts. The use of case study design as a methodology is most beneficial for this project as regards the analysis of the information, evidence, and data collected and generated from the three particular STEM activities examined.

The organization of this research is in accordance with factors typical for case studies, such as the need for a deeper exploration into the processes behind individual learning and that this exploration requires a deeper, intensive, and holistic description (Merriam, 1998) to better inform current theories of STEM learning. However, this holistic approach is not defined by purely qualitative methods and so the use of embedded case study methods (Scholz & Tietje, 2002) is deemed most appropriate. This research is driven by qualitative questions explored using both quantitative and qualitative analytical tools and analysis in order to better understand the implications of learning theories grounded on the merits of interaction-based learning and meaning-making.

Yin (2009) suggests that the use of case study design can be criticized for its lack of clearly defined techniques for case analysis; however, this limitation can be overcome by defining strategies and techniques that outline what is to be analyzed and why. This project is driven by the need to describe the nature of interactions within STEM activities in order to inform existing theories about why collaborative, experiential, and project-based learning activities may be conducive to fostering both subject knowledge and 21st century skills. For this reason, this project will follow a mixed-methods strategy driven by key theoretical propositions about STEM learning in the application of a pattern matching strategy of explanation building (Yin, 2009). This strategy applies findings from each case to evaluate how well the cases support or deviate from what STEM learning theories define as an effective STEM activity conducive to learning based on the identification of conditions for learning.

It is not uncommon to find the use of case study design when exploring the literature on STEM learning activities and environments. However, it is sometimes less clear how a case is determined when the context, STEM education, is a key component within the analysis of an embedded phenomenon. Some contemporary examples focus on teachers as the unit of analysis that distinguishes the cases (Altan et al., 2018; Kim & Keyhani, 2019), while other studies use the individual students as cases (Ayar, 2015; D.-Y. Park et al., 2018; Sriram & Diaz, 2016). Still other studies look at actual formal or non-formal institutional settings in which the STEM activity takes place as the case under investigation (Lynch et al., 2017). On the other hand, other studies use the actual STEM activity itself as the case wherein multiple strategies and techniques are applied to investigate learning phenomena about the participants and teachers within the STEM case (Ghanbari, 2015; Guzey et al., 2019; Toda et al., 2019; Vu & Feinstein, 2017).

These studies show that there is a fine distinction to be made when exploring STEM activities using case study methods, and that the distinction is not always clear between the STEM activity serving as the case, or as the context, for the individual cases. Furthermore, it is also unclear at what point of departure a study into STEM learning phenomena can be considered as a case study or if the use of this term belies a conventional qualitative methodology within a STEM context merely stipulated as a case. When looking at the merits of the actual STEM activity itself, it becomes less clear if a truly case study design approach is used because the methods are more aligned to intervention or comparative research strategies. Overall, it would appear that research into STEM that is focused on individuals (whether teachers or students) tend to apply a clearer explanation behind the use of a case study design approach, and that the suggested use of STEM activities as cases in-and-of-itself is perhaps better explained by the fact that STEM is still a relatively limited phenomena and therefore tied to methods that focus on limited contexts and available data.

The scope outlined within this research project is focused on individuals and not on the details of evaluating the actual STEM activity as an educational product or intervention. For this reason, and in line with much of the current STEM literature on students and teachers as cases, this study will also employ a case study design approach with the one set of units of analysis being the individuals within the cases. Although the individuals are a key element for structuring the analysis of the data, it is the contexts wherein each individual is situated that is referred to as a case as well, since each of the activities is unique in some distinct manner, and which serves to differentiate the individuals further. It is easiest to consider the individuals as subcases within the analysis and the context as cases from which the discussion of findings will be structured and organized. The use of a case study design that focuses on the individual interactions within a context for the purpose of relating to overall learning theories—which is usually the domain of other methods into STEM evaluation—is a somewhat novel approach.

4.5.1 Selection of the Cases

The three contextual cases explored in this research project are found within the same overarching thematic context of one particular non-formal STEM initiative. Although this context is situated within a non-formal STEM education non-profit, and conclusions can only be drawn specific to this one example, the learning theories related to STEM education are still relevant for exploring and understanding the general occurrences and events that take place within this context.

The three cases, although unique in some ways, are still collaborative, experiential, project-based activities using the integration of science, technology, engineering, and mathematics at their core. The subcases of students and mentors and the various interactions that they generate serve to inform the theories that are implicit within the design and deployment of STEM activities and environments and will reflect back onto the overarching context of the non-profit's particular design and approach to STEM activities, events, and workshops.

The cases were selected based on previous experience working with the non-profit over a number of other activities that later served as pilot studies in preparation for this formal investigation. Although various cases were explored over the course of three years from 2017-2020, only the cases that were amiable to the use of video-recording equipment were selected as cases to explore in this study.

This study focuses primarily on three thematically related STEM cases and the various subcases of groups and individuals that are encompassed by them. All of these cases were events organized exclusively by the non-profit and were not designed or structured by the researcher. The cases derived from the non-profit events display aspects of STEM, mentoring, making, active learning, experiential learning, collaborative learning, project-based learning, and the conscious pedagogy for developing 21st century skills. These cases serve as real-life, complex learning environments where the researcher has no control or role in manipulating the environment to suit the needs of the study. These activities are labeled as follows:

- Hackathon: Engineering Student Hackathon
- Training: Mentor Training Activity
- Workshop: Teachers and BBC Micro:bits

The first STEM context is a higher education student hackathon that lasted two hours and challenged the engineering student participants to build a light-powered vehicle that was programed by a BBC Micro:bit. The second STEM context is a mentor training activity that saw pairs of former hackathon participants accomplish a task based on the successful hackathon prototype. This mentor training case served to prepare the engineering students for mentoring other learners within the same activity. This second case lasted two-hours as well and was focused on only one pair of participants. The final STEM activity case is a workshop organized in cooperation with the non-profit and a Swedish school development program (SDP) to introduce Swedish secondary school teachers to the SDP's "thematic box". This box was a kit serving as a pedagogical tool to be incorporated into the teachers' classrooms as part of science, programming, or technology subjects. The case was based on one group of five teachers working together with each other, and their mentor, to build and program a vehicle using light sensors and the BBC Micro:bit.

Although each case is a varied iteration of the same general activity, there are circumstances within each case that can shed light on STEM learning within collaborative problem-based learning contexts featuring participants and educators at different stages of the STEM pipeline. For this reason, the cases within each activity can help contribute to knowledge about STEM learning theories that focus on subject knowledge, but also on how these activities can provide opportunities to practice 21st century skills that can be used to inform professional skills development in engineering education.

However, the STEM activity cases are limited in providing findings from direct comparisons of individuals or groups within each context. For this reason, it was not deemed necessary to collect data that could be directly linked to any one individual—that is, the data was collected anonymously without any personal data about the participants documented. The only comparative factor between the participants relevant for a QE analysis founded on Communities of Practice (CoP) theories, is whether the participant was a Swedish school teacher or an engineering student.

Within each STEM activity case, one group of between two to five individuals was selected based on the willingness of the participants to be subjects of audio-visual data collection. To state that the subcases were formally selected would be inaccurate; rather the exact members that would compile each subcase was based on self-selection. Each STEM activity featured a similar context with key details maintained from one activity to the next. These included: designing and building an electric vehicle that would be activated by light sensor input; the use of BBC Micro:bits for programing the vehicle; parameters to determine the best vehicle; working in separate groups; and a shop to purchase the parts chosen to build the vehicle.

When looking to differentiate the cases, there are two key variables or aspects that distinguish them, and which have relevance during the analysis of the data as regards the STEM activity epistemic frames and the units of analysis within the networks. First, the original hackathon case presented the participants with a very open-ended problem and with no official procedures to follow when compared to the latter two cases. Second, the first two cases featured participants that were studying engineering and computer science while the last case featured school teachers not formally trained as STEM professionals. For a more detailed outline of the STEM activity components, see Table 1 (on the next page) for a list of the participants, materials, contexts, and objectives of each STEM activity case. This list provides insight into the sorts of units of analysis and points of segmentation for the coding process that will be highlighted later in the methodology and analysis.

Table 1: Components of the STEM Activity Cases

Activity Details	Hackathon	Mentor Training	SDP Workshop
Theme	build a vehicle driven by light	build a vehicle driven by light	build a vehicle driven by light
Instruction	non-profit staff, university staff, engineering student peers	non-profit staff, workbook, engineering student peers	mentors, workbook, peers
Participants	engineering students, non-profit staff	engineering students from the hackathon, non-profit staff	Swedish school teachers, engineering student mentors, non-profit staff
Materials	Basic electronic components, BBC Micro:bit, tools, laptop	Basic electronic components, BBC Micro:bit, tools, laptop	Basic electronic components, BBC Micro:bit, tools, laptop
Context	University setting, evening	University setting, evening	University setting, morning
Duration	120 minutes	120 minutes	120 minutes
Features	separate groups, competition, no instructions, task delegation, materials shop, vague objective	separate groups, training, workbook, materials shop, clear objective	separate groups, training, workbook, task delegation, materials shop, clear objective
Activity Phases	plan, design, prototype, test, evaluate	plan, design, prototype, test, evaluate	plan, design, prototype, test, evaluate

4.5.2 The STEM Activity Non-Profit

Seeking accessibility to non-formal, well-organized, and willing organizational participants deploying STEM activities in the Stockholm area was quite limited. Through a contact at a Swedish higher education institution specialized in engineering in Stockholm, this researcher was introduced to one such non-profit, and was soon granted access to collecting data on the various STEM activities organized by this organization. The non-profit was an interesting case to investigate because in addition to the typical elements found within STEM education and STEM activity design, there was the unique aspect of involving engineering students studying at a Swedish university, specialized in engineering studies, serving as mentors for the STEM activities provided to local youth, young adults, and school teachers. Also, the non-profit had access to a university-based makerspace and its various industrial and often expensive fabrication resources.

The non-profit was founded in the mid-2010s by an engineering student and supported by an engineering educator at a Swedish university. The non-profit had a mission to provide non-formal and informal learning opportunities that could inspire and motivate communities to actively develop their knowledge and skills of modern digital technologies. This non-profit organized entertaining and often kid-friendly activities and workshops that introduced participants to topics such as computer programming, electronic systems, mechanical engineering, and the various practical components of design innovation such as user experience (UX) design, prototyping, and testing. The focus of these activities was to allow non-formal learners the opportunities to engage with maker culture, digital technology, electronics, and STEM career professionals.

The STEM activities were specifically aimed at underprivileged youth in some of Stockholm's immigrant-dense and socioeconomically deprived areas. The standard events would take part either in a local makerspace, or similar environments found at a university campus, local libraries, schools, or even community science centers. Like many STEM activities, the goal of these events was to try and spur the interest of at-risk youth toward education and careers in the STEM sector. This goal is not uncommon among other STEM initiatives, or within general STEM discourse about improving the leaking STEM pipeline for women and minorities.

The non-profit STEM activities usually centered on the building of a digital toy/artefact that required soldering electronic components such as resistors, capacitors, LEDs (light emitting diodes), transistors, integrated circuits, etc. onto printed circuit boards (PCBs). Coding embedded into the electronic system resulted in a particular action on the part of the digital toy. For example, one digital toy used infrared (IR) light to showcase communication using infrared spectroscopy as in the case of one popular STEM activity conducted by the non-profit for secondary school students. Other activities included the use of BBC Micro:bits and the teaching of basic computer programming.

In addition to short single day activities, the non-profit also organized multiple day summer schools and summer workshops, which allowed students to build functioning prototypes of complex mechanical devices that were programmed to respond to environmental stimuli such as sound, or more computer-based prototypes such as webpages. Some of the more popular activities also utilized simple motors to create small robot-like creations that could draw on paper or race along the floor. All of the various activities were meant to be simple, yet challenging, and most importantly fun and engaging with playful elements that could appeal to students from ages ranging from primary school to the tertiary level.

The STEM activities used engineering student volunteers, or students taking part in student exchange programs from partnering universities around Europe, as mentors to help activity participants assemble their digital toys. It was this mentoring role of the engineering students that spurred interest into better understanding the impact of mentoring combined with hands-on experiential STEM activities on the added skills and competences available to the tertiary-level engineering students, as well as the other activity participants. This interest resulted in the additional curiosity about the contribution of STEM for more than just the immediate participants (i.e., the mentees). That is, this particular non-profit spurred interest in determining what, if anything, was gained by the engineering students when serving as mentors in STEM activities.

The non-profit was working with the assumption that STEM activities are suggested to improve subject knowledge and 21st century skills for the engineering student participants, especially since the mentors had to take on more leadership roles that aligned with much of the professional skills needed in modern engineering careers. It is this additional mentoring aspect to this non-profit's STEM activities that made for an interesting context and selection of cases to explore.

However, despite the obvious advantage to having reliable and open access to existing STEM activities, the nature of using these activities meant that the control of the project was not solely at the discretion of the researcher. For this reason, the project worked within a set of practical and ethical boundaries that are not uncommon in collaborative researcher projects that take place in co-operation with other parties. This is especially true for research approaches such as action research, participatory research, industry-based research, or research on learning settings such as classrooms.

Unfortunately, as an indirect result of the coronavirus disease pandemic of 2019 (COVID-19), which stretched into 2021 and resulted in school closures and various social distancing practices in Sweden and the world, the non-profit was unable to continue its activities and would eventually undergo a formal process of dissolution and permanently close in 2020.

4.5.3 A Swedish School Development Program (SDP)

For the third STEM activity, the non-profit collaborated with a Swedish school development program (SDP) working to develop resources and competencies of school teachers specialized in science and technology classes within the Swedish compulsory education system. Despite this industry collaboration, the research undertaken within this project is not directly related to this specific program or its staff that was collaborating with the non-profit for this specific case. For this reason, any factors related to the SDP as an entity involved in STEM-related education is not considered within the scope of this study. Furthermore, the description of the teachers' workshop case is focused only on the activity organized by the non-profit and does not include details about any other SDP activities, or information about the teachers that the SDP selected to take part. However, some context is important to mention in order to better understand how this non-profit and SDP collaboration shaped the STEM activity investigated in case three of this research project.

The particular SDP involved in this case can be described as a school development program that provides competence development and guidance for science, technology, and mathematics teachers by providing teaching materials and other support. There has been one study that supports the claims of this SDP that their materials result in better learning outcomes when used by teachers in their classrooms (Anderhag & Wickman, 2007). The SDP was founded in the late 1990s by a collaboration between the Royal Swedish Academy of Sciences, the Royal Swedish Academy of Engineering Sciences, and over 70 municipalities and additional independent schools (Anderhag & Wickman, 2007).

One specific contribution made by the SDP that is most relevant to the research project discussed here, is the development and deployment of specialized *thematic units* that adopt an inquiry-based approach to learning. In the case of this research project, the concept of a *thematic unit* is understood in relation to commercial STEM resources such as 'maker kits' or 'tinker boxes' due to each thematic unit providing materials, instructions, activities, and learning outcomes similar to how commercial tinker boxes or maker kits do.

The collaboration between these two organizations was aimed at having the non-profit's staff develop an activity based on one of these thematic units and its accompanying materials—namely the BBC Micro:bit. This activity would help the school teachers to understand the SDP's thematic unit with the aim of incorporating the use of BBC Micro:bits into their science and technology classes to promote coding and computer programming lessons.

These teachers were situated within the latter three years of the Swedish compulsory education system, which is typically grades seven to nine (in Swedish: *högstadiet*). The SDP selected roughly 35 to 40 teachers from all over Sweden to take part in a training program that took place over several days and in various locations around Sweden. This training session was meant to engage the teachers in seminars and workshops to improve their science and technology teaching competencies, while also introducing them to new learning materials that could be employed within their classrooms. One segment of this training session brought the teachers to the city of Stockholm to take part in a two-hour Micro:bit training activity that took place at a local university campus. It was this activity that was designed and organized by the non-profit with only loose and general guidelines from the SDP. These guidelines were centered on featuring the use of electronic parts like sensors and motors that could be combined with the programming features of the BBC Micro:bit to build a digital artefact. Further details about the formal process that the SDP and the non-profit undertook to plan and construct the eventual activity, and its corresponding thematic unit/maker kit, were not documented within the scope of this research project for both practical and ethical reasons.

4.5.4 Case One: Engineering Student Hackathon

The first case involved a voluntary hackathon (i.e., hacking marathon) for engineering students that took place in the early evening of a weekday within the third month of the higher education autumn semester. The hackathon served as a forum from which the non-profit would recruit participating students to serve as mentors for the subsequent activities related to the hackathon.

A hackathon is a collaborative and innovative event held at a physical location where participants create software or hardware prototypes in an attempt to address an organizational or personal problem (Richterich, 2019). Despite their popularity and growth within technological organizations, their evolution from collaborative and skills-building events into competitive and temporally limited activities has resulted in limitations to their effectiveness for learning (Richterich, 2019). However, the context of the hackathon within this case was promoted to the participants as a non-competitive (i.e., no financial or occupational incentives) and low-stakes brief. The non-profit worked to promote the collaborative, creative, and knowledge-sharing aspects possible within a hackathon setting rather than the competitive ones.

In the autumn of 2019, the hackathon was organized by the non-profit and delivered to local engineering students at one of Sweden's Stockholm-based upper-secondary institutions. The challenge of the hackathon was to build and program a vehicle, using only the supplies provided within the activity, that would drive in response to a sensor and a subsequent motor being triggered by a light source—i.e., a simulated solar powered car. The supplies for the hackathon were part of an independent school development program's kit of teaching and learning resources that would be distributed to teachers in Sweden in the near future. Although the hackathon is primarily intended to provide the engineering students with an opportunity to practice and develop their knowledge and skills, the context of the STEM activity is determined by more than these pedagogical aims on the parts of the non-profit that organized it and the school development program (SDP) that commissioned it.

The additional purpose of the hackathon was to prepare engineering students to serve as potential mentors that would help at an upcoming event organized by the SDP. This event was a training camp for teachers from all over Sweden and would feature a workshop designed and delivered by the non-profit. The cooperation between the SDP and the non-profit in running and organizing the hackathon, and the subsequent workshop, was aimed at school science, technology/electronics, and programming teachers across the whole of Sweden in order to help them incorporate STEM activities into their classrooms by training them on how to use the SDP's science and technology kits. The kits provided by the SDP featured the use of BBC Micro:bits as the primary resource to help teachers implement programming activities within their compulsory school classes. This kit (a.k.a., thematic unit) included the electronic and digital supplies provided to the engineering students taking part in the hackathon.

As mentioned earlier, the overall goal of the hackathon was to build and program a digital artefact using only the materials supplied by the STEM activity organizers. The main components of the hackathon were to design, fabricate (both electronically and structurally), and program a light-controlled vehicle. The programming aspect was done using BBC Micro:bit hardware and its accompanying software interface that used either block coding (Microsoft MakeCode or Scratch) or a text-based programming language (Python editor or C++) to program the light sensors and trigger the mechanical motor on the vehicle.

The hackathon participants were placed in groups of between five to six students. There were not many "rules" to the hackathon, but the students had to find ways to distribute responsibilities for each task in the activity and to make decisions on what parts to use for the building of the car since they were only provided with the bare essentials and limited funds to purchase others. At the end of the hackathon, a winning team was selected based on low costs for building the prototype, how far the vehicle traveled in a designated time, and a vote on the general aesthetics of the vehicle. Although twenty students took part in the hackathon, not all of these students participated in the following SDP workshop as mentors.

This case was documented by collecting audio-visual data on one group of five engineering students that agreed to sit at the table designated for data collection. This table was recorded in a manner that was meant to be non-intrusive by keeping the recording equipment in one place and out of direct sight of the participants. One relatively small digital camera (GoPro) was mounted on a neighboring table and positioned to record the selected group from one stationary angle. An additional digital voice recorder was placed on the center of the group table to better capture conversations between the participants in the event the digital video camera was not able to.

4.5.5 Case Two: Mentor Training Activity

The second case was an offshoot of the hackathon case discussed above and which served as a preparation exercise for a following activity with the same general thematic exercises as found in the original hackathon. During the original hackathon, the participating engineering students were asked by employees of the non-profit to provide their contact information if they wished to be contacted to take part in an upcoming SDP workshop where they would take on the roles of mentors for a group of teachers that would take part in a similar STEM activity. Prior to serving as mentors for the upcoming SDP workshop, the non-profit planned to gather the mentors together and have them work in teams of two to complete a revised version of the original hackathon. This revised version of the hackathon would be completed by the Swedish school teachers as part of their participation in the SDP workshop.

The mentors were asked to not only complete the task, but to consider this exercise from the perspective of someone that would mentors others to do it. One pair of mentors was digitally documented with audiovisual recording equipment that was kept at a slight distance and incorporated into the environment in order to maintain an authentic experience during the activity. The activity was prefaced with an introduction by staff of the non-profit explaining the planned activity that would take place with the Swedish teachers. This was done to reiterate to the prospective mentors the intended role they would play in the upcoming teacher training workshop.

The mentor training participants were then given the materials for the activity, a workbook outlining the steps and objectives of the activity, and a bowl of fresh popcorn and told they could sit in pairs and begin. The activity was scheduled to take place over two hours but was generally unstructured with little to no instruction provided. This created a context where the engineering students were responsible for executing the aspects of the activity in whatever manner they chose, which included both the technical construction of the vehicle and the interpersonal conditions present within collaborative work.

4.5.6 Case Three: SDP Workshop for Swedish School Teachers

The third and final STEM activity case was situated within the SDP workshop for Swedish school teachers and was organized by the non-profit with visible collaboration from the school development program. The non-profit developed a STEM activity using the pedagogical supplies provided by the SDP and which would be included in an SDP thematic unit about electronics. This case is the main focus of this research project as there are many aspects present that serve as a basis for comparison with the above two cases. Furthermore, this last case provides more facets and variables from which to glean insight into STEM education and STEM learning due to the potentially wider range in STEM knowledge amongst the participants.

As part of the preparations before the STEM activity was delivered, the data collection equipment was placed in the activity location in advance of the participants' arrival. With the exception of introducing the digital video, voice, and proximity sensing equipment into the environment, there was no other formal intervention or involvement of the researcher in the preparations or the delivery of the STEM activity. The arrangement and locations of the recording equipment was determined based on minimizing the intrusive nature of their presence and to not create physical or psychological barriers for the participants when taking part in the STEM activity. This decision about the location of data collection instruments may have resulted in limitations about what could be heard and observed at all times; however, it was deemed that preserving the authenticity of the STEM context was of higher importance than perfect or controlled data collection strategies.

After initial disclosure and discussion with the selected group of participants was conducted regarding the digital recording equipment, there was no more active attention to this detail during the activity—for example, asking participants to remain within frame of the video camera. The group of teachers that was documented as the subcase for the SDP workshop was self-selected by the participants based on their decision to sit at the table designated as the data collection site. The composition of the group was determined by an SDP organizer, who segmented the teachers into groups of five and had them take seats at each station (i.e., table). The engineering students serving as mentors were already seated at each of the tables, with the mentor situated at the data collection table aware that they would be documented for research purposes.

The data collection group featured a mentor that did not speak Swedish and who was not a native-English speaker despite a respectable command of the English language. This mentor self-selected to be the subject of data collection by volunteering to mentor the targeted subgroup. This selection was formally made on the day of the activity despite all mentors being informed that they could be asked to participate in data collection prior to the workshop.

When it came to the self-selection of the teacher participants that would take part in the STEM activity as members of the subcase, the mentor's use of English was a key determining factor. The teachers that would be the subjects of data collection required a level of comfort with having to speak in English with the mentor, and ideally with each other, so as to not exclude the mentor at any stage. To ensure the mentor was involved with the teachers over the duration of the activity, it was communicated by the staff of the non-profit that all group discussions, even those not formally involving the mentor, should be communicated in English. However, following this initial disclosure regarding the language conditions for taking part in the data collection group, the participants were not instructed again regarding their language use so as to not disrupt the authenticity of the context. This was held true even in the event that the teachers spoke Swedish.

4.6 Data Collection Methods: Audio-Visual Data

This study is driven by data generated with the use of video recording equipment, which resulted in materials that are "rich in temporality and multimodality" (Yang, 2023, p.97). There are various methods and video tools used in capturing human behavior and each strategy comes with its own limitations, strengths, and ethical dilemmas. Earlier pilot studies conducted to determine the best method of data collection revealed that collecting data from formal assessment or self-report strategies, such as the use of questionnaires, proved ineffective in answering what was truly at the heart of inquiry into the conditions for learning within STEM activities.

The methodology outlined below presents the use of video recordings as a data source for multimodal interactional evidence. Also, this section discusses how this particular strategy can contribute to the literature on STEM learning by providing justification for data collection that can yield more detail and information than what can be collected by other means such as observation protocols or research journals alone.

Advances in modern technology have allowed for video-recording equipment to become more affordable, smaller in size, with higher resolution images, and more user-friendly; however, examining visual information derived from video-based data is still a relatively underutilized approach within the social sciences regardless of the substantial potential such methods present in the capturing and representation of human behaviors within natural and authentic contexts (Heath et al., 2010).

The use of video equipment to capture human behavior is not unlike other forms of 'social sensing' found within Big Data collection and analytics, which brings to light the high degrees of cognitive load experienced by researchers attempting to make sense of such large amounts of information captured in videos (Tay et al., 2017). This of course relates back to the challenges address by the automated processes of QE and ENA within this project and how the nature of QE research is often related to large-scale data generated via digital means.

Despite the challenges of using video data in research, the use of video data also presents an opportunity to use more flexible and open methods of analysis, such as qualitative document analysis (QDA), in the reviewing of the data and in the identification of coded objects for ENA analysis. The sheer amount of information captured by moving images allows for less stringent adherence to only those strategies deemed suited to a particular type of data (e.g., visual, verbal, multimodal, text, etc.). While QDA does not drive the overall methods of this project, the use of QDA is meant to add a layer of transparency to the process of coding the conversations and interactions between the STEM participants and their environments. Furthermore, QDA is amiable to case study design and is quite flexible by allowing for thematic, content, and discourse analysis procedures to accomplish a wide range of goals such as selecting statements for ethnographic approaches or grounded theory, and for providing clearer frameworks for coding and analysis (Wood et al., 2020).

As is the case with thematic analysis in general, this approach is quite vague and does not provide very clear guidelines or frameworks for the process (Bryman, 2012). However, despite much of the literature on quantitative ethnography and epistemic network analysis overlooking details about how themes are identified and translated into code, it is important to provide more information about this stage of the coding in light of the qualitative nature of the audiovisual data. Furthermore, due to the importance of how coding reflects discourse among the participants while also providing fairness to underpinning theoretical constructs, an iterative approach to coding is found to be most suitable when transcribing and segmenting the data from broad to more narrow coded elements (Shaffer & Ruis, 2021).

The use of document analysis to explore video data to extract and identify themes for coding into quantitative data allows for transparency, reflexivity, and increased rigor (Mackieson et al., 2019). Qualitative document analysis also allows for a wide array of data to be used in light of documents being able to range from text, to still images, to videos. Lastly, the iterative approach to coding also impacted upon the later analysis of the findings by allowing QDA to feature in deriving thicker descriptions of what was taking place within the video source data that was underpinning events or phenomena identified during the initial quantitative analysis of the networks. Therefore, the QDA was paramount in associating meaning to findings from the ENA, which help to close the analytical loop in understanding the STEM activities in terms of how the participants displayed or adopted both STEM knowledge and 21st century skills. The repeatable playback afforded by video data during iterative stages of the analysis, both prior to and after conducting the epistemic analysis, showcases the strength and richness of replayable information in the form of raw, archival, and digital audio-visual formats for a QE methodology influenced by Big Data research techniques.

4.7 Other Sources of Data

This project also collected data beyond only video recordings of the STEM activities in action. However, many of these data collection strategies provided only complementary data to support or triangulate assumptions and understandings of the main audiovisual data. For example, an anonymous online creativity questionnaire was distributed to all the participants of the SDP workshop, both engineering students and teacher participants alike. The aim of this questionnaire was to collect feedback and self-reported data about creativity employed within the activity. Infrared (IR) sensing badges were also used in the activity in an effort to capture aggregate network data about general interaction patterns of the groups that were the focus on the data collection. Both of these instruments, unfortunately, collected data that was of only peripheral value for the investigations of this research project.

Furthermore, due to the onset of the COVID-19 pandemic, integral data collection strategies had to be abandoned prior to the full conclusion of data collection for the STEM activities. The resulting COVID-19 restrictions on face-to-face meetings and quarantine practices due to illnesses among various parties, meant that a planned multimodal focus group meeting was not conducted with the engineering students that took part in any of the three cases.

Despite this setback, the research project was adjusted to accommodate these setbacks, which meant that much of the additional data collected was reserved for use to support the audiovisual data or stored for use in future research or publications.

Below are elaborated explanations of three complementary data collection instruments. Although the data collected from these instruments was not used in the formal analysis, these strategies did manifest within the data collection environment, and are therefore important to disclose to maintain practical and ethical transparency of the full research methods used for this research project.

Infrared (IR) Proximity Sensors

The cases in this study also served as opportunities to test a prototype of IR proximity sensors deployed in the environment to document movement of the participants as they navigated the STEM activity and the various stations designated within the context. The IR proximity sensors were anticipated to collect data about which, when, and for how long a signal-emitting sensor worn by a participant was in proximity to a signal-receiving base station found at other group tables, the “shop” (a station where participants purchased building supplies and electronic components), and the non-profit’s staff table.

The aim of using passive sensing data to document physical interactions of this nature was to explore the potential value of sensing data in educational contexts to provide another parameter to analyze and conceptualize interaction data without having to use more complex and disruptive equipment in the environment. The data generated by the proximity sensors is not reliable enough to be included in this study, but it did provide another point of verification of observations that individuals interacted within their own groups at their own tables, but did not interact with other participants found at other group tables.

Laptop Screen Recording

Within the first engineering student hackathon case a laptop computer was provided to the participants subject to audiovisual documentation in order to capture data about the coding procedure of the activity. It was anticipated that discussions about generating the code could be viewed and interpreted alongside a screen recording of the code as it was written. The purpose of this auxiliary data collection was to provide clarity for the verbal discussion about programming the BBC Micro:bit in the event it proved too abstract or difficult to understand without the aid of a visual reference.

However, although conversations about the coding was captured with the conventional tools, the participants decided not to use the provided laptop and chose to use their own. Because the methodology aimed to keep the STEM environment as organic as possible, there was no interjection made to insist on the use of the provided laptop. In the end, this data was not deemed necessary for the analysis because the audiovisual data captured enough quality information about this stage of the STEM activity.

Digital Questionnaire

After the completion of the third STEM activity case with the Swedish school teachers, a digital questionnaire was provided to the teachers to complete as part of a reflection exercise after the activity was over. All of the teachers completed the questionnaire and although the answers were anonymous, the findings from this instrument worked to compliment some of the interpretations gleaned from the analysis of the audiovisual data on the one group examined in greater detail. The inclusion of this instrument was meant as a compliment to the video recordings and to allow for participants' responses to provide another perspective, a subjective perspective, on some of the key components present in the SDP workshop case—namely claims for the manifestation of creativity epistemics.

One of the claims underpinning the methodology of this research project has been a critique of self-report data in capturing valid and reliable data about what objectively takes place within a STEM activity with respect to displays of subject knowledge and opportunities to practice 21st century skills as conceptualized within the 4C's framework. Therefore, the data collected from the questionnaire gathers important opinions about how the teachers reflectively perceived the SDP workshop as a STEM activity that is collaborative, creative, enjoyable, hands-on, and informative. The self-reported feedback provided a source of information that could triangulate the presence of abstract cognitive epistemics in the coded audiovisual data.

The questionnaire was designed based on several existing instruments used in previous research on 21st century skills and STEM activity feedback (e.g., Torrance Tests of Creative Thinking, the Partnership for 21st Century Skill framework) and in particular with guidance from an instrument that was piloted in other research just prior to this research project commencing data collection (see Kelley et al., 2019).

4.8 Data Analysis Tools and Techniques

This section outlines the applicability of Epistemic Network Analysis (ENA) for mapping the interactional data within the video recordings that captured participants and mentors collaborating within their STEM activity. The method for video transcription will also be detailed, in addition to outlining the coding and preparation of the data for use within the online ENA analytical tool and nCoder. Along with the use of conversational-based ENA models, the analysis also aims to provide temporal segmentation of the data (Siebert-Evenstone et al., 2017) and coding of multimodal actions (Ruis et al., 2018) to further elaborate on the interactions that take place within the activity beyond co-occurrences of information from utterances alone.

The overall value of ENA is to provide a manner to quantify and visualize the structures and strengths of connections present within a network of objects, both in the form of aggerate profiles and to identify changes in the configuration and strength of these networks over time (Shaffer et al., 2016). The aim of these network visualizations is to envision the co-occurrences between coded epistemics of STEM cognitive knowledge and 21st century skills. Furthermore, by coding multimodal interactions between participants and mentors, a network of knowledge contribution and sharing can be developed to better map how STEM learning takes place in solving complex problems collaboratively. The networks generated from ENA analysis allow for comparisons between coded relationships, in this case either epistemic or multimodal, for each of the participants, which can shed light into the epistemic frames each participant harbors and utilizes in their cooperation with others in the various stages of an experiential learning activity.

The ENA method and tool also allows for the direct comparison between various networks. This means one is able to compare network models generated based on different units of analysis (e.g., people in the activity or stanzas), which allows for greater exploration of the STEM activity contexts in an iterative manner. When comparing network models, ENA either superimposes networks on top of one another or creates a subtracted cognitive network model. The former allows for direct visual comparison of the networks and the latter draws out the most striking differences between them.

Furthermore, because the phenomenon of learning is associated with the development of the epistemic frame for the STEM activities in these cases (and a potentially new model for STEM which includes making and mentoring as based on this ENA), it is possible to frame the research questions and their references to learning within the methodological perspective of quantitative ethnography. What this suggests is that the QE conceptualization of learning becomes represented by an analytical space that is generated by the participants. That is, the analytical space generated by an epistemic analysis reveals how the data from the participants results in a sort of situated CoP specific to the STEM cases explored in this study, which relates to a data-driven development of a potential understanding of learning in STEM activity contexts.

The application of ENA tools is based on the purpose of wanting to focus on the connections that take place between skills and knowledge within the STEM activity cases instead of looking at affective assumptions about how they may relate, or how frequently they are referenced. Hence, the decision not to use multivariate analyses or even other methods such as correspondence analysis (CA) or principal component analysis (PCA). Both CA and PCA are useful methods for understanding interactional data and connections between factors, but fail to situate visualization outputs and models within a comparative dimensional space as the ENA method allows (Bowman et al., 2021). This implies that while CA and PCA can provide information about the inputs of a learning context and suggest some relational explanations about patterns or relationships amongst these factors, these methods cannot provide much insight into understanding processes that may contribute to learning, or to generate a representative model of the construction of a learning context on anything more than just these basic input factors.

4.8.1 Selecting and Transcribing Video Data

Over the duration of the STEM activity cases, over 80 hours of video recording was generated. When resources permitted, multiple cameras were trained on one group in order to capture more angles and to ensure less gaps or interruptions in the camera line of sight to the participants. A disadvantage to the data collection was the occasional lack of complete data for an episode of data collection due to the cameras running out of battery power or participants moving out of frame. Furthermore, as no data collection method is without its flaws, there are obvious moments where the audio is unclear and not available for reliable transcription. This is especially the case with the engineering student hackathon activity where camera equipment ceased to function before the completion of the full activity resulting in a failure to capture the final testing iteration of the activity. However, the latter two stages of data collection allowed for power supplies within reach of the camera equipment and which resulted in full video capture of these particular events. The video-source data was accompanied by audio recordings of the activities, which were collected in the event the video data audio was difficult to hear or understand. This means that if there was difficulty to hear audio from the video data, the audio data could be used to help better define and transcribe what was communicated but not well captured in the video.

One important development that took place over the course of this research project was the increased use of automated transcription methods and the greater reliability of AI generated transcripts available to researchers. However, despite the availability of such software, it was deemed unhelpful for the data generated from these cases because the verbal communication was often too dynamic, complex, and messy for accurate automated transcription. Also, the raw data was far too complex in contextuality and nonverbal cues to foster meaning to the verbal utterances. All of the data was transcribed in the traditional, and labor-intensive process, of having an unaided human listening and watching the raw audiovisual data and transcribing what was seen and heard.

Translations and Transcriptions

The first stage of transcription was focused on the mere verbal conversations taking place between the participants. A verbatim transcription was first prepared in whatever original language was used by the participants (i.e., Swedish was used on occasion in some cases) and then translated into English. The transcriptions serve as the textual data to which epistemic object codes are analytically assigned. For instances of Swedish transcriptions being translated, the transcription and its source video were presented to a local Swedish research group to ensure accuracy of translation. No mistranslations were detected even if there was a potential conflict in interpreting meaning from tone and other social signaling, which went beyond the verbal translation itself. The reviewed English translation was imported into Microsoft Excel and a file with ENA formatted tables was created (see Table 3 in section 4.8.4).

Although not an overt facet to this research, there is an undoubtable cross-cultural element to the STEM activities and the resulting transcription process. The STEM activities utilized both the Swedish and English languages, and the transcriptions are analyzed based on their English translations. There is a potential problem with trustworthiness of the transcription translations due to the conflict between the Swedish national and linguistic context of the STEM activity cases and the use of the English language during the data preparation and analysis. To address this problem with cross cultural research and qualitative transcription of verbal and non-verbal utterances in Swedish, this researcher sought local expertise within a relevant research group to ensure the English transcriptions reflect the cultural representation of Swedish-speakers without allowing for English cultural preconceptions or mistranslations (Arunasalam, 2019; Kamler & Threadgold, 2003).

Audio-Visual Transcriptions

The transcription of the data focuses on three elements: 1) conversations; 2) physical gestures; and 3) navigation of the environment. The first element of conversations produced talk-based verbatim transcriptions of all that was said over the course of an activity by all of the participants. This verbal transcription was limited by the feasibility of what could be extracted from instances of participants talking at the same time or when some utterances where completely inaudible. The second aspect of transcribing physical gestures was recorded less systematically than the conversations, and focused on selected instances of analytical interest based on a qualitative document analysis technique. Finally, the documentation of how the participants navigated the environment focused on identifying details of how the participants interacted with the various physical materials provided to them (e.g., electronic components, computers, etc.) and the activity workbook if provided. When all three of these data transcriptions of conversational and interactional data are taken together, the multimodality of the activity can be examined and even coded for further analysis using ENA methods and webtools.

Video transcription software, Transana Pro, was used to compile and code various data sources in order to provide clips of information for analysis and coding into ENA formatted tables and cooccurrence matrixes. The use of Transana allows for codes and timestamps of video data to be linked with transcriptions of verbal communication, as well as combining other data sources such as still images and documents to the analysis. This proved important when understanding and attempting to code what participants were referencing when using the workbook to support more effective communication about potentially complex aspects of the activity.

The selection and use of Transana Pro software was driven by an analytical model that requires the data to be segmented into collections where relevant video clips are stored along with transcriptions of the verbal or multimodal interactions that take place within a reasonably similar temporal context. The use of keywords and keyword groups allows for coding to be linked to a theoretical structure that represent concepts as 'Codes of a Discourse' for both STEM knowledge and 21st century skills. The software Transana allowed for similar coding and transcription methods to be exported into Microsoft Excel for further conversion into a format readable for the ENA webtool. This use of ENA to frame the analytical model for transcription in Transana was to ensure a smooth transition of the transcribed data into ENA format for ease of later interpretation using epistemic network parameters.

Using Transana Pro allowed for the display of four simulations windows showing various ways of tracking and transcribing the source data (i.e., video recordings). This was useful for returning to sections of the source data when attempting to identify multimodal or explanatory features to expand upon the analytical understanding of what was taking place within the STEM activities. See Figure 3 for a screenshot of the Transana Pro software in use and the four windows displayed during use. All four of these windows are linked using timestamps, which make it is possible to trace and identify the locations of video images or audio recordings associated with a particular transcription or keyword. The upper left window shows the audio spectrum (Visualization), the lower left window is where the timestamped transcription is created (Transcript), the upper right is where the source data is played (Video Media File), and the lower right window displays the entire database of data and keyword organization (Data).

Having the source data linked to the transcriptions in such a manner allowed for more flexibility when undertaking the transcription process. Playback of the videos, and even slowing down this playback, ensured more accurate transcriptions. Furthermore, it was possible to enact a mode of direct transcription of multimodal or spoken information when establishing keywords, which meant that the transcription procedure for multimodal documentation could be more efficient. For example, after all of the talk information was transcribed and timestamped, it was possible to return to segments of the source data via the transcription and insert keywords directly into the transcriptions that were used to later identify key multimodal actions or epistemic displays. This mode of transcription was also important to maintain the abductive process in understanding the STEM activities from multiple points of interest.

It is important to state that Transana does not store the video data files but rather links the locations of data files stored on more secure local devices using pathways. These pathways must remain the same (i.e., data files used in Transana must stay in one digital location on a device or computer) in order for Transana to link the data to transcriptions with the media files. This allows for added security for the source data, but also requires more diligence to not lose work done using the software.

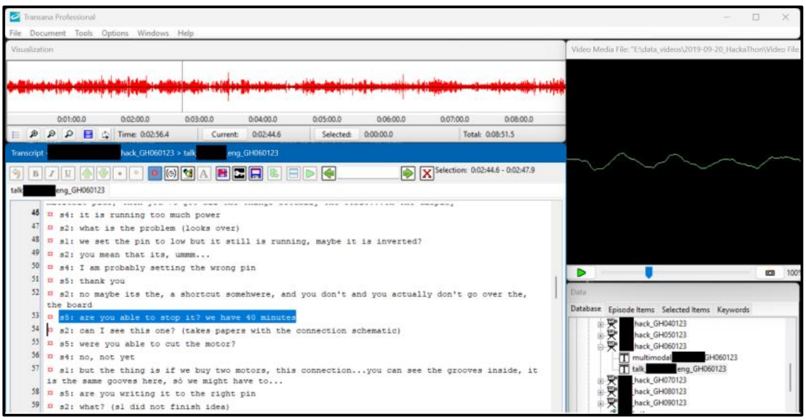

Figure 3: Screenshot of Transana Pro
Transana user interface featuring the interconnected Visualization, Transcript, Video Media File, and Data widows. (Black redactions were added to this image to maintain anonymity of the case featured in the image).

Not all of the source data was transcribed, however, and it was important to consider the selection of data in terms of the validity of the epistemic frames that ENA creates to represent each case activity. For this reason, complete conversational data transcriptions for each case were used to establish the epistemic frames, which implies that a great deal of attention and care was used in transcribing all talk-based utterances within each case. Once the entire verbal transcription was complete, analytical segmentations of the data were applied using keywords to denote, for example, distinct roles in the activities.

For later interpretation of the various stages of each STEM case, a preliminary selection of key activity units first segmented the data into sequences that capture a feasible quantity of data to represent distinctive aspects of interaction, conversation, and navigation of the STEM environment. Each distinct stage of the STEM activities must also be accounted for and so audio-visual data was selected to showcase stages such as planning, prototyping, testing, and debugging/solving malfunctions or mistakes. Each of these sections are what is termed a *stanza* according to the coding system employed for ENA analysis.

4.8.2 Identifying Coded Epistemics within the Transcriptions

The codes are compiled both before and after reviewing the data in a typical iterative process essential for the sort of *thick description* (Geertz, 1973) used in Quantitative Ethnography. That is to say, some themes are sought within the data and the transcriptions based on previous research and theory while other themes and codes are generated as a result of exploring the data. The former is especially important for working to identify the manifestation of 21st century skills while the latter is more closely linked to the various STEM knowledge-based epistemics that come out of the verbal conversations and hands-on activity of design and fabrication of the artefactual outcome of the STEM activity.

Generally, the identification of coded epistemics followed a pattern of code selection that combined the use of three approaches useful for epistemic networks: theory-based approaches; insight-based approaches; and model-based approaches (Árva et al., 2023). This aligns with the use of an iterative coding process that is informed by existing theories, previous research, and a continued revisitation of the source data on multiple occasions before, during, and after developing network models using ENA methodologies. Simply put, the original epistemic codes for STEM knowledge constructs and 21st century skills enactment were guided by relevant literature, while the ENA webtool allowed for insight into the data for identifying more succinct codes underlying the original constructs. Lastly, the application of a model-based approach allows for any potential findings to be further refined and to generate improved parameterization of STEM learning opportunities within the context of the cases examined in this research study (Árva et al., 2023).

As briefly mentioned earlier, another feature within the transcription of the data in Transana is the use of Keywords. The assignment of keywords within the Transana transcription process allowed for easier application of the ENA webtool. Simply put, these keywords reflect the epistemic codes that are used by the ENA tool to frame and structure the STEM activity models. The first open coding of the talk-based transcription based on keywords allowed for a record of words and utterances that could be used to reflect the codes for STEM knowledge constructs and indications of 21st century skills being applied to the activity on the part of the participants (i.e., theory-based approach).

The next stage in preparing the data for ENA was to review the transcripts and to code the utterances according to the selected epistemic codes in order to prepare a relational data table that can be formatted for the ENA webtool. A random selection taken from the entire transcription is presented below (see Table 2) to showcase how transcribed talk was associated with keywords and especially coded epistemics—a larger sample of this coding table is provided in the Appendix. This table provides a brief example of how the transcribed talk (and minimal multimodal) data was associated with the coded epistemics for STEM knowledge and 21st century skills. This is part of the first stage of coding, and is referred to as the theory-based approach.

Table 2: Sample of Coded Epistemics
Coded Epistemics were assigned based on transcription utterances.

Utterance (lines 568 - 639)	**STEM .sci**	**STEM .tech**	**STEM .eng**	**STEM .mat h**	**TCS.c omm**	**TCS.c reat**	**TCS.c rit**	**TCS.c oll**
Task nine					Task nine			Task nine
yes					yes			yes
microbit...task nine...task...nine...task nine...theeee...micro-bit...there we go		micro bit						
just let me...i think we need to disconnect the		di-scon-nent					I think	we
ok...why?					why			ok
oh, can we...ok let me try the (takes microUSB and attaches it to the device on the table)		Atta-ches it to de-vice			Oh… ok		Let me try	Can we
fair enough...here is the mirco...USB (hands it to S2 who in turn plugs it into the intake device on the table while S1 plugs the other end into the laptop)	Plugs it in…ot her end into lap-top				Fair enou gh			(hand s it to)
alrighty...ok this thing does not make any sense (indi-cates something to non-profit staff that has just walked over to the table)...this should be a range			Shoul d be a range	range	Ok…		Does not make any sense	
yeah, (scratches head) i know, there might...there are different thresholds that can work		thres holds	Thres holds that	Diffe-rent thres holds			There might be…	

Utterance (lines 568 - 639)	STEM .sci	STEM .tech	STEM .eng	STEM .mat h	TCS.c omm	TCS.c reat	TCS.c rit	TCS.c oll
			can work					
i know but it doesn't make...this should be a range (pointing to so-mething in the workbook)				range	I know but…		It does n't make sense	poin-ting
yeah but for your code you need one number, right?		code			Yeah but		You need one num-ber, right?	

The specific codes and epistemics based on STEM knowledge and 21st century skills are the main focus for the quantitative ENA portion of the analysis and where targeted for identification after the initial coding of the data. This was done using a deductive approach with predetermined codes being sought within the raw data. The codes are divided into two general categories: STEM Knowledge (STEM.); and 21st Century Skills (TCS.). Within each category there are four specific constructs. Under the STEM knowledge category are found the constructs for: science (STEM.sci); technology (STEM.tech); engineering (STEM.eng); and mathematics (STEM.math). Under the 21st century skills category are found the constructs for: communication (TCS.comm); creativity (TCS.create); critical thinking (TCS.crit-think); and collaboration (TCS-collab).

The STEM constructs could be identified with greater ease with a coding schema that required less interpretation than what was needed for 21st century skills constructs. For coding the 21st century skills constructs, a more process coding approach (i.e., insight-based approach) was required in order to capture performative aspects of words and actions based on communication, collaboration, creativity, and critical thinking.

When deciding on the presence of a construct based on the textual data it was important to remain consistent with understanding words based on their contextual meaning to determine their validity as a representative construct of the determined code (Linneberg & Korsgaard, 2019). For example, the *meaning* of a word or utterance required a reflection on its relationship to the construct code. For example, the word "count" does not necessarily imply a mathematics construct unless the context and use of the word itself alludes to a connection to a mathematical computation instead of being used as slang to indicate consideration.

Finally, the iterative nature of the project and the unique features of recorded audiovisual data allowed for subsequent coding of the data using a more inductive coding approach (i.e., model-based approach). The model-based approach was applied to the exploration of constructs that emerge from the data, and that could elaborate on the findings from the original ENA in order to contribute to a more exhaustive understanding of the STEM activities.

4.8.3 The ENA Webtool (webENA)

The ENA Webtool is accessible online at https://www.epistemicnetwork.org/. The webtool is free to use, however, access is granted only after the creation and validation of a user account. The use of this webtool requires the following statement of acknowledgment about the use of the epistemic network analysis (ENA) product:

This work was funded in part by the National Science Foundation (DRL-2100320, DRL-2201723, DRL-2225240), the Wisconsin Alumni Research Foundation, and the Office of the Vice Chancellor for Research and Graduate Education at the University of Wisconsin-Madison. The opinions, findings, and conclusions do not reflect the views of the funding agencies, cooperating institutions, or other individuals.

The reference above to "this work" indicates the webENA webtool specifically and is not meant to suggest that this research project is itself funded by the abovementioned actors.

The webENA tool comes with support from the creators and various tutorials in the forms of online videos, seminars, manuals, and a step-by-step tutorial that helps new users through the processes of uploading data, selecting units of analysis and other key data categories, and selecting the parameters for generating the epistemic network plots and statistical tests. An added feature to the webtool, which was not originally present, is the option to generate written statements about the plots to ensure that researchers new to the method are able to interpret the results correctly—this feature was not formally utilized within the project and any similarity between what could be complied by the webtool and what is written within this document is most likely the result of coincidence, and the fact that instruction on ENA has been provided by the same sources.

The ENA webtool cannot be described in exhaustive detail here, but the general features will be mentioned with respect to how this tool was applied in the analysis of the STEM activity data. Below is an image of the webENA opening page with the list of projects associated with one user. Prior to venturing further into the webtool, the first instructions that are presented to the user help to prepare their interpretative lens when considering details of the analysis and the sorts of information that is meant to be highlighted. As seen in the upcoming image (Figure 4), the webENA tool indicates that an ENA model will require data defined according to Units, Conversations, and Codes.

The webtool provides a helpful indication if these conditions are met when preparing the analysis, and also provides flexibility in how units of analysis and segmentation can be altered depending on various points of interest in the investigation. For example and in reference to this research project, it is possible to prepare the data to focus on individual participants within the STEM activities, or this can be changed at a later point to prepare network models for segments of the activity itself instead of the participants within it. This flexibility in manipulating the units of analysis without compromising the transcriptions or the source data allows for comparative investigation to take place in an iterative manner across different points of curiosity.

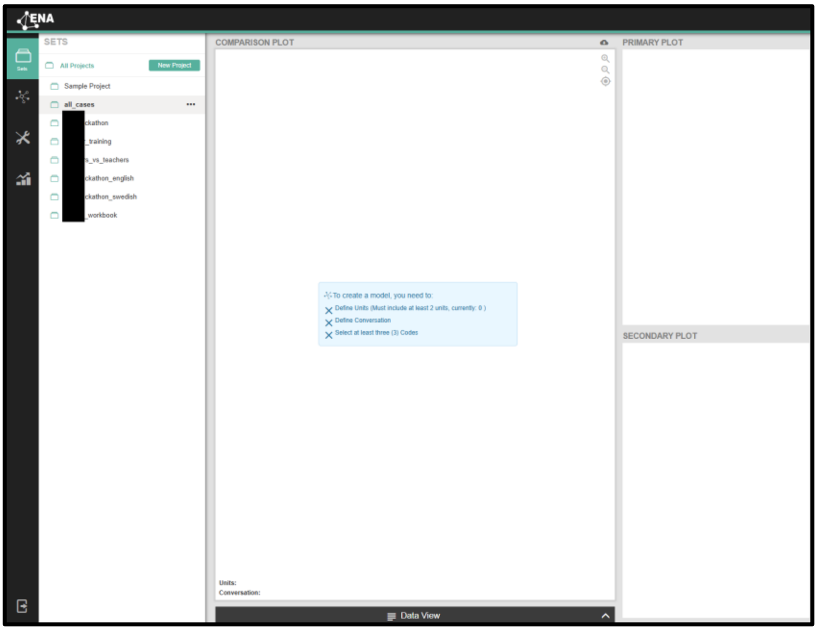

Figure 4: Screenshot of webENA

Webtool showing the steps that need to be taken to create an ENA model using the guided tutorial function. (Black redactions added later to conceal possible identifying information about the source data.)

The webtool is also sectioned into four key windows/tabs along the left side of the opening page where the user can bring to the forefront the data sets, the models that have been generated, the plot tools, and the statistics for the plot. This allows the user to see the various constraints applied to the data within the plots, what the plot is highlighting, and even the network statistics associated with the plot. The Plot Tools window allows for the user to make specifications such as the dimensions of the plot along the x-axis and the y-axis as regards the variation of the singular value decomposition (SVD). The labels that are visible for the Plotted Points can also be selected based on what units are highlighted in the analysis for each plot. Finally, the Network Graph can also be manipulated to determine the scaled and weighted parameters for when connections should be highlighted by edges between the coded units. All of the decisions that can be made using these features are used based on the knowledgeable analytical decision of the researcher and can be ignored for the sake of defaults for less experienced users. The research project outlined here decided against using the more advanced features of the webENA tool, but did make use of some features to better highlight the nodes and edges of the network models—e.g., making node circles bigger or edge lines thicker.

The Model window/tab in the ENA webtool serves as a visual representation of what units and activities are present in the network model, and to see what data is present within each unit (e.g., text or subcategories). The user is also able to select colors to identify each unit and to add or remove units from the dynamic plot generated at the center of the webtool screen. Depending on what information about the plot is determined to be necessary for the analysis, the user can select whether or not to include confidence intervals and means for each unit within the plot. The only aspects of the plot that cannot be manipulated—based on the use of the webtool within the scope of this project—is the epistemic frame itself, which is the space along the x-axis and y-axis within which the network plot is positioned.

The network plot is represented at the center of the webtool screen and is referred to as the Comparison Plot, as it allows a dynamic selection of various units to view the various facets of the model by hovering over them with a mouse/curser. This brings to the surface and makes visible the edges that represent connections and relations between nodes in the network and the identified unit of analysis. The webtool also allows for two network plots to be selected and displayed on the far right of the webENA screen in the Primary Plot and the Secondary Plot sections. These two plots, the primary and the secondary, are also highlighted on the overall comparison plot as well. This dynamic aspect to the webtool allows for quick and multi-faceted analysis of a relatively large set of data due to the network representations and the manner by which one or two of these networks that are present in the epistemic frame can be highlighted for comparison. This also makes it possible to explore the data according to the connections between the units of analysis and discover interesting patterns that can be used to spur deeper analysis.

The comparison of the various network connections that are present among the various units of analysis in the data can be done beyond a visual interpretation of the network plots, or even a basic review of the network statistics. An added component of the webENA tool allows for statistical analysis of the networks and the connections to determine, among other things, the statistical significance behind patterns or comparisons of the plots. The webtool allows for both parametric and non-parametric comparison statistical tests to be run on two units of analysis and their resulting networks, as well as offering statistics such as goodness of fit and variance for the comparison plot or the selected networks within it. Below is an image of webENA according to the sample data provided for tutorials. This sample data, and the associated training tutorials, help users to generate images using the functions of the webtool and to understand how this can result in detailed ENA models that may be easier to interpret.

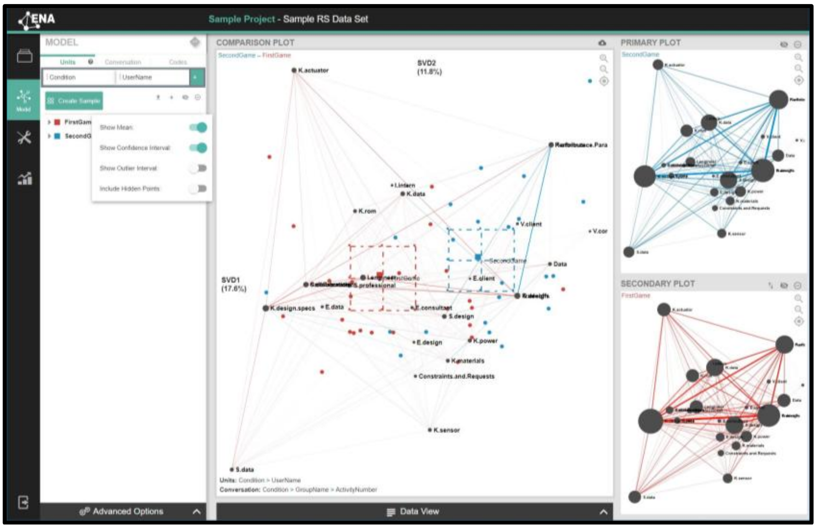

Figure 5: Sample of Formatted ENA Models
ENA models may be adjusted or formatted using webENA, and the tutorial resources provided within the tool, to highlight node and edge strengths.

WebENA requires that data is formatted in a specific way prior to being imported into the webtool as a New Project—this is discussed in detail in the following section Formatting Data for ENA Analysis (4.8.4). In the case of this research project, the ENA formatting was done by exporting transcription files from Transana Pro and importing them into Microsoft Excel. One Excel workbook, with various spreadsheets that highlighted different units of analysis or various segmentations of the original data, was generated for each separate STEM activity case that was examined. Each New Project accounts for the different spreadsheets by having different folders within each project for the data tables that were segmented or organized differently to capture different perspectives on the data, and to generate findings for various analytical questions. Having each case within a separate project meant that each case was analyzed individually and any interpretations of the findings from each analysis were later combined within an overall discussion about points of interests and comparison that were apparent within each case analysis.

4.8.4 Formatting Data for ENA Analysis

According to Shaffer (2014), the key elements of information that are essential for conducting an ENA analysis include: the *objects* that are the focus of the network model; establishing *relations* between the objects; coding units of data, in this case *stanzas*, that quantify the links between the objects; and an association to data that provides *evidence* in identifying the relations within the network model.

Representing an epistemic network analysis requires formatting data in a specific manner that can enable all of these key elements to model the two separate and yet related functions that take place to the data within the ENA analytical tool: 1) stanza-based network models; and 2) the analytical space where these models can be compared (Shaffer, 2014). Although network models are intuitively familiar, the space onto which this network is projected is perhaps not.

This analytical space is unique to ENA and is also referred to as the epistemic frame, which is visualized in ENA analysis as a projected analytical space onto which networks are positioned and compared. This epistemic frame is derived from the theoretical foundations of how quantitative ethnography views learning in terms of connections between constructs rather than the mere presence of these constructs within the network. The importance of how this relates to the formatting of the data rests with how connections between codes are identified and assigned based on binary formats that represent underlying adjacency matrixes for all of the coded epistemics that cooccur between the network objects and stanzas.

Although the complexity of how ENA translates formatted data into network models and the analytical space is beyond the scope of this research, a very brief explanation can help in understanding the formatted ENA tables and the data they showcase. In the very least, the key elements of an ENA formatted table must include columns that represent metadata (such as student IDs, activity unit batches, and stanza raw data such as transcribed conversation or multimodal information) and code columns that represent co-occurrences and their strengths using binary units that reflect more complex adjacency matrixes.

The upcoming table displays a small section of formatted data that highlights these columns of data prepared in ENA format (see Table 3). The table presents the three main data structures that help to organize the data when conducting analysis. The first two of these data structures are under the metadata column and the third indicates the coded columns. These three main structures in Table 3 are the units of analysis (e.g., Unit or ID), how an activity can be separated into various temporal elements (Stanza), and how the object codes can be formatted as binary data despite communicating more complex cooccurrence matrixes (Coded Columns).

Table 3: Example of ENA Formatting
ENA formatting identifying the coded columns for Metadata Columns and the Coded Columns (sample data taken from the SDP teacher workshop case).

METADATA COLUMNS					CODED COLUMNS (OBJECTS							
	Stanza	**Unit**	**Raw Text**	**ID**								
Line	**Activity**	**Group (pg.#)**	**Text**	**Part**	**STEM.sci**	**STEM.tech**	**STEM.eng**	**STEM.math**	**TSC.comm**	**TSC.coll**	**TSC.creat**	**TSC.crit**
107	Program	9	What is a good number to use as a threshold when the Micro:bit needs to decide if there is light flashed on the sensor or if it's just the ambient light it detects?	blue	0	1	0	1	0	0	0	1
108	Program	9	Ambient light < Threshold < Flash light	blue	1	0	0	1	1	0	0	1
109	Program	9	(blank) < (blank) < (blank)	blue	0	0	0	1	1	0	0	0
110	Program	9	Why are these numbers different than the ones you measured at task 6?	blue	1	0	1	1	1	1	0	1
111	Build	10	Connect the motor to the Micro:bit through P1.	blue	0	1	1	0	0	1	0	0
112	Program	10	Write the code so that the motor starts when the output from the light sensor is larger than the threshold you defined on Task 8.	blue	0	1	1	1	0	0	0	1
113	Program	10	When the light sensor output is lower than the threshold the motor should stop.	blue	0	1	1	1	1	0	0	0
114	Program	10	In other words, the motor goes only when there is light flashed on the light sensor as described in the flowchart below.	blue	0	1	1	0	1	0	0	0
115	Program	10	Too hard to figure out? Find a hint towards the end of the workbook	blue	0	0	0	0	1	1	0	0
116	Program	10	(image: Verticle flowchart that shows No and Yes conditions that are written on arrows that extend up and down from a central item that asks if light is flashed on the sensor. The No and Yes arrows point toward either Motor OFF or Motor ON for the respective conditions) located along the right side of the page under the text for Task 9	blue	0	0	1	0	1	0	0	0
117	Experim ent	10	Why doesn't the motor work??	blue	0	1	1	0	1	0	0	1
118	Tinker	10	The output of the Micro:bit is not strong enough to start your motor.	blue	0	1	1	0	1	0	0	1
119	Tinker	10	For the motor to work you first need to amplify the signal from the Micro:bit using an amplifier.	blue	0	1	1	0	1	0	0	0
120	Tinker	10	Keep reading to find out more about the amplifier.	blue	0	0	0	0	1	0	0	0
121	Tinker	11	What is an amplifier?	blue	1	1	1	1	0	0	0	1

In order to apply the use of ENA analytical tools and techniques, it is vital to establish a valid and reliable framework of concepts that can be coded within the video data in terms of both conversational and observational information. It is this framework that is reflected in how the data is formatted into codes, sections, and activities. The latter columns of the formatted data that are populated with ones and zeros reflect a framework of concepts about STEM learning and 21st century skills because these object codes are used to develop the epistemic frame for the STEM activity cases in this study.

The formatted data in this study was produced in a Microsoft Excel spreadsheet and later imported into the ENA analytical tool, although alternative methods that use automated processes to code and prepare the data using the eCoder package supplied with the ENA web tool (ENA WebKit v. 4) can also be used. The data itself comes from transcriptions and keywords created and assigned using Transana Pro. Exporting Transana transcriptions into relational data that can be prepared for ENA formatting within Excel can be laborious depending on how much data is present, and how this data is coded and segmented within the ENA framework. There are various adjacency matrixes that need to be generated to summarize strengths of relationships that occur between the various coded constructs, and which need to later be converted into binary data within the stanza-based matrix.

The coding process, therefore, has a series of steps in data formatting to ensure that the ENA software can read the data and generate appropriate tables and visualizations. Although other network formats exist, they do not account for the analytical space that is generated in ENA, and which allows for comparisons between the networks as a result of this formatting (Shaffer, 2014). Other forms of network analysis do not allow for comparing network models due to lacking this analytical space, but also make coding and formatting data easier as they are not based on cooccurrence matrixes.

The process outlined above allows for a standard ENA of conversational data that results in networks for the entire unit of an activity. In order to compare more than network models of epistemic or multimodal frames, a temporal aspect to the processing of the data needs to be accomplished. By moving away from the content of utterances to the connections made between turns of talk, connections can be mapped to reveal how student discourses are connected over units of temporal segmentation (Siebert-Evenstone et al., 2017).

This data formatting procedure requires recoding data according to a "moving stanza window method" (Dyke et al., 2012), which allows stanza units to overlap and form connections over turns of talk in a knowledge "uptake" (Suthers & Desiato, 2012) that is otherwise hidden within aggregate connections that are revealed over the course of an entire activity or part of an activity. The importance in making connections between turns of talk that might not take place within a standard one-on-one, back-and-forth, style of communication, is that it allows for a better account of individual contributions to collaborative group conversational dynamics. The use of moving stanza windows allows one to trace how ideas are processed and evolve over time as a conversation develops and leads into other topics. Although there are established statistical test that can account for variance between individual variables or participants, such as t-tests or ANOVAs, these quantitative evaluations do not account for the collaborative influences that any one individual may contribute to an overall group discourse or dynamic (Cress & Hesse, 2013).

Another aspect of segmentation that takes place within the data occurs in a more theoretical and practical manner. This refers to how one overarching activity can be organized and segmented into various sections. For example, one STEM activity can be divided into the various specific tasks that are meant to be accomplished, which requires more input and direct influence from the researcher. On the other hand, segmentation of the activity can take place on a more intuitive level based on time, days, or even individual turns of talk.

ENA Formatting and Cooccurrences of Epistemic Codes

As stated earlier, the aim of using ENA is twofold: 1) to generate visualizations and network statistics that can compare how each STEM activity, when examined according to various units, creates patterns in interactions; and 2) to generate other sets of analytical output that can explore how the individuals related to each other over various stages of the activity and how there can be possible changes over time as the activity progresses. The use of ENA provides a quantitative overview of the whole STEM activity from various analytical perspectives that account for the dynamic, complex, and temporal aspects that shape STEM education, and which can inform and relate back to general frameworks for STEM teaching and learning.

In the upcoming discussion about how the ENA webtool uses formatted data, a table (Table 4, p. 102) presents a section of the ENA formatted data showing how turns of talk (i.e., rows within the table) are grouped by different types of segmentation of the STEM activity (e.g., activity [Act.] and section [Sect.]) and how the coded epistemics are assigned to each row—this table is obviously not the complete file used for ENA. What is important to note, is that the segmentation of the data into a 'moving stanza window' is not indicated within the formatted table, but rather is a computational segmentation conducted within the ENA webtool irrespective of the analytical segmentation of thematic stanzas presented in an ENA formatted spreadsheet such as what is displayed in Table 4. The stanza window automatically groups raw data, such as turns of talk, temporally rather than thematically.

The upcoming table (Table 4) also shows a sample of one STEM activity spreadsheet divided into only some of the separate stages of the activity as a whole, which include: organizing the group roles; designing the vehicle; writing the code for the Micro:bit; completing the questions within the workbook; putting together the electronics; and tracking the budget. Within each of these stages, the transcription data is the source of the epistemic codes, which are indicated on the right by ones and zeros. Therefore, determining which epistemics are present within each segmentation of the activity is dictated by the conversational and interactional data rather than data segmentation. This same procedure applies to both the STEM subject knowledge and the 21st century skills epistemics.

What results from identifying an epistemic within the transcription data is a list of ones and zeros that indicate the presence or absence of one or more epistemic within a turn of talk. However, how these epistemics cooccur over the moving stanza window is, again, determined within the ENA webtool. Also, the binary information (ones and zeros) merely represents if epistemics are present within a turn of talk, and not how many times they are indicated within that turn of talk or segmentation. To account for how many times the same epistemic is mentioned would require a weighted ENA, which was not conducted because the data presented very little need for a weighted consideration with it being very infrequent that one epistemic was present more than once in each stanza.

Within the ENA webtool, the binary data of the spreadsheet actually reflects adjacency matrixes indicative of the relations that occur with all of the epistemics, which means that the binary data is actually a reduction of information from a more complex cooccurrence matrix. How the matrixes are prepared for ENA analysis is presented in the following section on how the ENA webtool uses the formatted data (4.8.5) in a way that understands the conversion of matrix data into binary format.

What is important to note when considering the segmentation of ENA formatted data, and the representation of coded epistemics according to this segmentation, is that the data can be examined based on the coded epistemics as they are present in each stanza when framed within separate units of analysis such as speakers or stages of the activity. Within this research project, in many cases the unit of analysis is an individual participant within the STEM activity, however, in the case of the STEM activity workbook, the unit of analysis becomes each stage of the activity itself. This ability to segment the data in various ways, and to also change the units of analysis, makes it possible for ENA modeling to showcase epistemic cooccurrences from various different analytical perspectives. This is because the allocation of the epistemics is determined within the raw data, which means that any segmentations of the data (e.g., any way that a STEM activity is conceptually organized or divided up) are understood by the cooccurrences of the coded epistemics (e.g., the way that knowledge and 21st century skills cooccur).

Regardless of units of analysis or segmentation, it is important to understand that for ENA, the epistemic frame that is generated from the cooccurrence data is important to interpret before it is then examined from the perspective of one or more units of analysis. This epistemic frame is only possible to generate due to how the ENA webtool and the ENA formatted data represent cooccurrence matrixes within the binary formatted table columns.

4.8.5 How the ENA Webtool Uses Formatted Data

As stated earlier, the mathematical complexity behind how ENA prepares summary statistics and network visualizations is beyond the scope of this research. However, below is a brief explanation regarding how the formatted data and their corresponding underlying matrixes are used to generate quantitative information and complex multidimensional network models used in analysis. This allows for using quantitative statistical analysis to support the visual interpretations made regarding the connections depicted within a network model. On a rudimentary level, ENA formatting converts cooccurrence matrixes into mathematical and visual representations that allow for the statistical comparison of networks based on content rather than basic structure (Bowman et al., 2021).

The data presented in Table 4 is structure to represent stanzas as an activity-based interactional network divided based on the type of actions taken by the participants. According to Quantitative Ethnographic methodology, the stanza-based interactional data "refers to information about a set of *objects*, the way they *relate* to one another, and a series of *stanzas* which reveal *evidence* about the relations between the objects" (Shaffer, 2014). With direct reference to this research project, the stanza-based interactional data can be simplified as: organizing information about the *STEM activity participants* (objects) and how their *interactions influence other participants* (relate) based on what *part of the activity or role they undertake* (stanza) and how the *cooccurrences of knowledge and skills* (evidence) takes place at those times or when taking on particular roles and when influenced and shaped by their fellow group participants.

Table 4 highlights only a small excerpt of this data, which means that only the immediately available stanzas for this small portion of data are available to provide an example of how segmentation occurs on the basis of simple turns of talk taken between the participants. The different stanzas in this sample are coded by segmentations of: 1) code; 2) design; 3) prob (problem solving); and 4) tinker. It is possible to also consider the sections of the activity (e.g., CODE, ELEC; DES) as segmentations of the data, but this is an analytical decision applied at the discretion of the researcher and which showcases the multiple variations of analysis that ENA enables.

The object codes (i.e., the coded epistemics) represent the following STEM knowledge and 21st century skills constructs: science (sci); tech (technology); eng (engineering); math (mathematics); comm (communication); creat (creativity); crit (critical thinking); and coll (collaboration). The activity codes were taken from 'small-d' discourse analysis and were derived from the data. The object codes were predetermined as key elements that are included in the STEM activity processes. The evidence is found within the raw text column of the data and the relations are represented by the binary symmetrical occurrences of the codes within the text.

Table 4: ENA Formatted Spreadsheet
Microsoft Excel spreadsheet with a sample of the data from the engineering student hackathon case in a simplified ENA format.

Line	Act.	Gr	Transcription	Sect.	sci	tech	eng	math	comm	creat	crit	coll
353	prob	s1	then why did we buy a light sensor	ELEC	0	1	1	0	0	0	1	1
354	prob	s4	i don't know	ELEC	0	0	0	0	0	0	1	0
355	design	s3	but we have to put the boards on so it's... we have to consider the boards, we have to put boards on	ELEC	0	1	1	0	1	0	1	1
356	code	s5	the response is reading the light values	CODE	0	0	1	1	0	0	0	1
357	code	s1	did you write the code or the blocks? i am sure you wrote the code	CODE	0	1	1	0	1	0	0	0
358	code	s4	no blocks (laughs)	CODE	0	0	0	0	1	0	0	0
359	code	s1	which one did yoy choose (the value for the light)	CODE	0	0	0	1	1	0	0	1
360	design	s2	we can use two of these ones to make sure they are at the same (motions with hands "height")	DES	0	0	1	1	1	1	1	0
361	design	s3	yes	CODE	0	0	0	0	1	0	0	1
362	code	s4	let's print in the line with the...	CODE	1	1	1	1	1	1	0	1
363	prob	s1	my questions is why do you need...a light sensor	ELEC	0	1	1	0	0	0	1	0
364	tinker	s5	a light sensor. maybe this is more, i don't know many it is access (points to light sensor)	ELEC	0	1	0	0	1	0	1	1
365	tinker	s4	because to access (picks up the device) so the sensor is covered	ELEC	0	1	1	0	1	0	0	0
366	tinker	s1	are you sure (as s4 looks over the deivce)	ELEC	0	1	0	0	0	0	1	1
367	prob	s1	because I didn't see a light sensor there seperately, I think you can still use this, can you just run the code	ELEC	0	1	1	0	0	0	1	1

Table 5: Sample of Adjacency Matrixes
Adjacency and cumulative matrixes for lines 363 and 364 from Table 4.

Line 363: Adjacency Matrix (Table 4)

Line 363	STEM.sci	STEM.tech	STEM.eng	STEM.mat	TSC.com	TSC.creat	TSC.crit	TSC.coll
STEM.sci		0	0	0	0	0	0	0
STEM.tech	0		1	0	0	0	1	0
STEM.eng	0	1		0	0	0	1	0
STEM.mat	0	0	0		0	0	0	0
TSC.com	0	0	0	0		0	0	0
TSC.creat	0	0	0	0	0		0	0
TSC.crit	0	1	0	0	0	0		0
TSC.coll	0	0	0	0	0	0	0	

Line 364: Adjacency Matrix (Table 4)

Line 363	STEM.sci	STEM.tech	STEM.eng	STEM.mat	TSC.com	TSC.creat	TSC.crit	TSC.coll
STEM.sci		0	0	0	0	0	0	0
STEM.tech	0		1	0	0	0	1	1
STEM.eng	0	0		0	0	0	0	0
STEM.mat	0	0	0		0	0	0	0
TSC.com	0	1	0	0		0	0	0
TSC.creat	0	0	0	0	0		0	0
TSC.crit	0	1	0	0	0	0		0
TSC.coll	0	1	0	0	0	0	0	

Lines 363-364: Cumulative Adjacency Matrix (Table 4)

Cumulative (Line 363-364)	STEM.sci	STEM.tec	STEM.eng	STEM.mat	TSC.com	TSC.creat	TSC.crit	TSC.coll
STEM.sci		0	0	0	0	0	0	0
STEM.tech	0		1	0	1	0	2	1
STEM.eng	0	1		0	0	0	0	0
STEM.mat	0	0	0		0	0	0	0
TSC.com	0	1	0	0		0	0	0
TSC.creat	0	0	0	0	0		0	0
TSC.crit	0	2	0	0	0	0		0
TSC.coll	0	1	0	0	0	0	0	

The coded object columns within the formatted data reveal only the cumulative binary data for each line despite ENA constructing adjacency matrixes for each stanza. This process is not revealed to the user of the ENA analytical webtool, but Table 5 shows samples of the adjacency matrixes for two stanzas when defined as simple turns of talk. These two stanzas reveal how complex the binary data can become as the stanzas increase in number within a typical application of ENA methods.

The importance of identifying the complexity of the matrixes is to ensure an understanding that the coded epistemics are registered as cooccurring along the stanzas, and not merely demonstrating their presence as could be suggested by a simple binary indication. Also, presenting only two lines in Table 5 does not show the true complexity behind the cumulative matrix that is calculated for one stanza window, which includes five lines or turns of talk, for each stanza window and its respective cumulative matrix.

Within the ENA web tool, network models are generated using these adjacency matrixes in combination with the selection of subjects to compare along an analytical space calculated by variance between the object matrixes. When comparing the epistemic networks for this very limited data, it is possible to identify some patterns in how the participants communicate. The key assumption behind the use of ENA is that it is more important to identify connections between cognitive elements (i.e., epistemics) than it is to merely record their presence or absence in isolation from one another (Shaffer et al., 2016). It is this focus on connections between bits of knowledge that underpins the ideas behind how quantitative ethnography and epistemic network analysis have developed their view of learning as a process (Shaffer et al., 2016).

In the next stage of analysis, the ENA web tool generates and situates the interactional data for each unit of analysis (in this case individual participants) on their respective positions within the analytical space. This analytical space is generated by the web tool by calculating the variances between all of the adjacency matrixes for the network nodes as a whole, which allows for the space itself to be interpreted. The importance of the adjacency matrixes is also imperative for understanding how the ENA web tool constructs and positions networks and nodes on the analytical space. This is done in a fashion that allows for the structures of the network connections to become more important and visible than merely the summations of weighted connections that may obscure subtle distinctions between similarly weighted, yet structurally distinct, network models.

The need for ENA to construct cumulative adjacency matrixes for stanza-based interactional data is based on how ENA translates this data into basis vectors that position each unit of analysis, and its coded cooccurrence within a cumulative matrix, within a high-dimensional space that contains all possible adjacency vectors accounted for in the stanzas (Shaffer et al., 2016). The adjacency matrix for each unit of analysis is simplified into a vector coordinate indicating the strengths of cooccurrences for this unit of analysis across all the stanzas and across all possible paired combinations of the coded epistemics—for this research project, the ENA is working to reduce 28 dimensions of data based on 8 coded epistemics.

In order to produce a simplified two-dimensional space where the network models are plotted, a dimensional reduction is performed using singular value decomposition (SVD). The use of SVD creates a space that is framed by values along vertical and horizontal axes that account for the largest patterns of variation that occur within all the possible cooccurrence in the stanza-based interactional data. This results in an interpretative, albeit reduced, analytical space where network models can be projected and compared based on the locations of their nodes. The more closely the nodes are situated, the more similar their patterns of cooccurrence between the coded epistemics are, and the further they are apart the more different these patterns of cooccurrence may be.

Although this may sound complicated mathematically speaking, this step can be understood more simply as all of the connections made between the coded objects for each stanza are being used to create points with values along both an x-axis and y-axis to construct the analytical space. This analytical space is data-driven and represents the source data rather than some abstract or theory-based space that is not related to the data at all, and which cannot allow for a comparative frame. This allows for network comparisons because it is this analytical space that remains constant despite various selections made about what units of analysis or stanzas are used to generate a network model. Basically, this analytical space (also referred to as the epistemic frame) contains all possible network models based on various units of analysis, which allows for coded object codes and their corresponding nodes to be placed in fixed positions based on the entire source data used in the analysis.

4.9 Automated Processes in ENA: nCoder, rhoR, and Speech Recognition

Modern technology affords researchers ways to streamline data processing and introduces a new methodological question into research practice about the use of artificial intelligence (AI) and software tools to transcribed or code larger sets of data quicker than can be done using manual processes.

Within the epistemic network community, there is work being done to explore and apply the uses of AI-driven (Artificial Intelligence-driven) speech recognition and language processing techniques to generate analytics in a manner that is faster than can be done when relying on the manual transcribing and coding of complex data (Zhao et al., 2024). However, these techniques also introduce errors in output that require a level of scrutiny similar to outputs from manually transcribed and coded data. For this reason, the application of modern AI-driven technologies and techniques are still in their infancy and therefore not applied within this research project.

Computerized AI transcribing and coding notwithstanding, there are several automated procedures and techniques within QE and ENA methods that are currently utilized, and meant to make larger amounts of data more feasible to work with while also attempting to limit errors in research validity and reliability. For example, there is a software package available to help with automating the coding process called *nCoder*, and there is also another tool called *rhoR* that calculates a value for interrater reliability (IRR) between this automated process in nCoder and manual (i.e., human) coding (*QE Tools*, n.d.).

The learning analytics platform called nCoder helps the use of ENA to be more efficient by reducing the need to manually code large amounts of raw data. This is accomplished by applying "cutting-edge statistical techniques to establish the reliability and validity of codes" that automatically implements a coding scheme for the whole of the dataset without the need for manual coding (*nCoder*, n.d.).

This tool, although potentially valuable when applied correctly to data conducive to this technique, was not suitable for the data used in this research project. The data, both raw and transcribed, was far too complex due to the combine audio-visual and human and non-human actors involved in its generation. For this reason, it was deemed necessary to manually code all of the data regardless of the amount of source data and transcriptions this involved. In Figure 6, there is an example of the nCoder package being applied to generate an automated coding scheme for the scientific knowledge epistemic (STEM.sci). Despite not using nCoder to formally assign codes to the transcribed data, the use of nCoder was useful in helping to provide a way to determine IRR for the coding schematics and operationalization of the STEM and 21st century skills epistemics.

Coding epistemics in a reliable manner is an important aspect of the ENA method, and so requires a technique to test the level of agreement between one, or more than one, rater. A rater refers to a human or non-human reviewer of the data that is applying a coding scheme to the data transcription in order to assign the coded epistemics to samples of raw or transcribed data. To ensure that codes are reliable, the creators of ENA made available a tool to check the IRR as regards how the epistemic coding is assigned within test samples of the data. This online tool is called rhoR, and uses a metric referred to as Shaffer's Rho to address the possible concerns for Type I error in interpreting IRR metrics, which are often computed in ENA based on tests sets extracted from larger dataset with limited variability in code constructs (Eagan et al., 2020). Type I error results from an underestimation in the level of agreement between raters because standard calculations for IRR, like Cohen's Kappa, can be manipulated by large amounts of data that feature relatively few codes (Eagan et al., 2020).

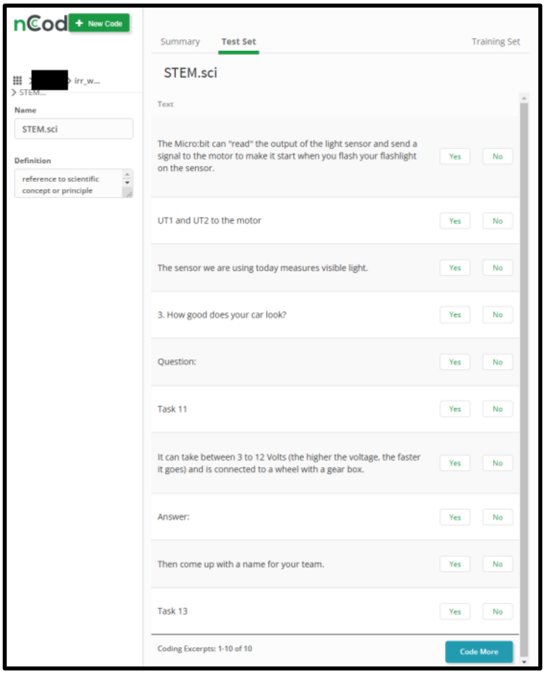

Figure 6: Screenshot of nCoder in Use
The data is taken from the SDP teacher workshop case and shows how the nCoder package is used to generate an automated coding scheme. (Available from https://app.n-coder.org/)

Metrics for *Shaffer's rho* and *kappa* were calculated when comparing the coding of two raters reviewing 25 randomly selected lines of transcription, which equates to roughly 15 percent of the total 168 lines of transcribed text from the randomly selected sample of transcriptions from a randomly selected segment of the data. The value for *Shaffer's rho* was 0.00 and the *kappa* value was estimated at 0.75, showing a precision of 0.97 (see Figure 7). The IRR values were calculated by using a contingency table of agreement and disagreement in coding between two human raters (see Figure 8), but was not calculated for a comparison between a human rater with the automated nCoder dataset as the use of nCoder was not applied for generating an automated coding scheme.

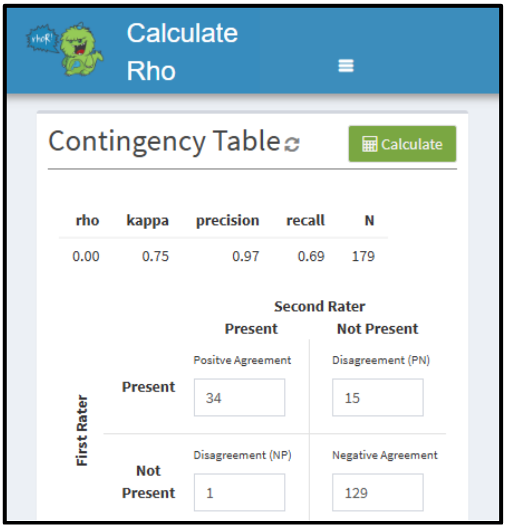

Figure 7: Kappa and Shaffer's Rho Estimates

WORKBOOK TEXT	R1	R2	R1	R2	R1	R2	R1	R2
	STEM.sci	STEM.sci	STEM.tech	STEM.tech	STEM.eng	STEM.eng	STEM.math	STEM.math
The motherboard is used to connect the Micro:bit with all the other electronic parts.	0	0	1	1	1	0	0	0
By plugging the micro:bit in the edge connector you get easy access to all the available input and output pins (P0-P20).	0	0	1	1	1	1	0	0
On the motherboard there are also 3V and GND pins you can use to power the different sensors and electronics of the kit.	0	0	1	1	1	0	0	0
Task 4	0	0	0	0	0	0	0	0
Plug the Micro:bit in the motherboard and connect the batteries.	0	0	1	1	1	0	0	
(image: top view of motherboard with micro:bit connected and an arrow pointing downward in the direction of connecting the micro:bit) located on bottom half of the page and slightly left aligned	0	0	1	1	0	0	0	0
Light Sensor	0	0	0	0	0	0	0	0
A light sensor is a device that takes light as input and gives a different value as output depending on how strong the light is.	1	0	1	1	1	1	1	1
This is done by converting photons into an electrical signal.	1	1	1	0	1	1	0	0
By measuring that electrical signal we can understand how bright the light is.	1	1	1	1	1	0	1	1
In our case the output signal will be higher, the brighter the light is.	0	0	0	0	1	1	1	1
There are different kinds of light sensors that can measure visible light, infrared or ultraviolet light.	1	1	1	1	1	0	0	0
The sensor we are using today measures visible light.	1	1	1	1	1	1	0	0
(image: photograph showing a top view of the light sensor) located to the right of text	0	0	1	1	0	0	0	0

Figure 8: Sample of IIR Contingency Table

4.10 The Qualities of a Qualitative Perspective

The QE community often addresses the importance of “closing the analytical loop” in order to generate qualitative thick descriptions of contextualized learning processes that are not possible to uncover with the use of quantitative models alone (Prieto et al., 2021). It is this final and critical analytical step that is meant to derive meaning from the three cases examined in this research project with respect to STEM learning activities in general. Although ENA is only one instrument within the QE methodology, it is adopted within and beyond QE approaches.

The application of ENA within this research project was encouraging because of the affordances of the ENA webtool to allow for the sort of cyclical scrutiny of the network models that contribute to the generation of thick description, while also providing a manner to enhance the trustworthiness of this qualitative stage of the QE process. This methodological approach can expand the analytical power of the findings beyond the limits of the specific cases selected for this study.

As stated earlier, this project is a mixed-methods endeavor that is meant to accomplish two specific goals that are important for a complete analytical cycle of QE. Firstly, the method of quantitative ethnography melds the two approaches together by quantifying qualitative data in a manner that goes beyond traditional mixed-methods approaches of triangulation or deeper investigations of quantitative findings in later stages of inquiry. Secondly, in addition to the use of ENA, another analysis inspired by Qualitative Document Analysis captures information and insights that cannot be incorporated into an ENA analysis that is focused on network patterns and structures.

The use of QDA is generally quite flexible and allows for investigating both *documents* in either visual or textual formats, and tangible three-dimensional *artefacts* that the participants interact with in an environment (Merriam & Tisdell, 2015). This aligns well with the audiovisual investigation into how the participants converse and interact with each other and their environments within the STEM activities. Furthermore, conducting a QDA, is a way to ensure a systematic uncovering of themes within documents, and to establish a qualitative triangulation of information to generate more trustworthiness to the findings of a study (Morgan, 2022).

For example, although this research project generates support for a methodology where multimodal data can be incorporated into the ENA analysis when coded appropriately, it can perhaps lose some meaning when attempting to discuss the overall ways that learning in STEM can take place beyond an interactional model or perspective. However, it is precisely this portion of the project that elaborates beyond the limitations discovered from ENA analysis and allows for reference back to source audio-visual data to better understand the implications of the ENA findings. The richness of the video data gets lost in the ENA coding process and can benefit from a more discursive analysis that can focus on nuances in human interactions and learning that cannot be relayed in objective or quantitative terms alone. One manner by which to allow for a qualitative element to video-based data is to embrace the multimodal perspective of viewing the captured activity. This allows for identifying one way in which communication using various modes can be linked to learning as an integrated meaning-making domain (Bezemer & Kress, 2016).

The current state of applying a multimodal perspective comes for the learning analytics tradition instead of one that looks at multimodality from a social-semiotic perspective. Multimodal Leaning Analytics (MMLA) combines log data from computer mediated interactions, which is typically the focus of more traditional learning analytics, with real-world data that captures human signals such as gestures, gaze, speech, or writing (Ochoa, 2017). The capture of video data serves as source data from which log data can be generated. In this research project, log data becomes verbal utterances or non-verbal modes of communication. However, the ability to enrich the transcribed data with qualitative interpretations of multimodal actions within the video data meant that a thicker description of the STEM activity would include ways of thinking and behaving that were not communicated directly and more objectively. The application of a more qualitative and interpretative content analysis was especially useful for instances where no verbal utterances were being made, and yet where it was possible to determine important cognitive or reflective activity was being conducted by the silent and mostly inactive participants—e.g., writing code, tinkering with electronic components, or reading the workbook.

Exploring the qualitative aspects of the data comes from the QE methodology for closing the analytical loop and seeking thick descriptions from the information and analysis conducted quantitatively, or with the use of ENA specifically. For example, when referring back to the data and working on ways to identify relations between knowledge and soft skills, a deeper examination of some of the connection (or lack of expected connections) was required. This qualitative analysis took the form of returning to the source data and identifying information within the activities what would shed further light on the patterns of interaction determined from the ENA networks, which displayed the connected ways of thinking and acting within the STEM activity cases.

The flexibility of incorporating QDA into an iterative methodology like QE serves two purposes. First, QDA provides another perspective to understand and interpret the source data to produce a multimodal layer to the transcription of the STEM activities. This added layer to the transcriptions captures information about how learning may be taking place in the STEM context than what more objective “log data” of verbal utterances can provide. Second, the application of QDA provides an interpretative method for investigating the source data associated with analytically interesting or relevant findings that come out of the quantitative ENA. Both of these applications of QDA provide a method for closing the analytical loop and to better identify, interpret, and analyze the conditions for learning that are present in the STEM activity cases.

4.11 Limitations to the Study

This study was limited by the affordability and feasibility of conducting an exploratory research project into non-formal STEM activities in several way.

First, it proved expensive and unlikely to design, staff, and deploy a STEM activity within either a school or non-formal setting within the scope or timeframe of this research project. This approach would have ensured more control over the STEM activity, its environment, and data capture; however, the complications of formulating this sort of study would have ended up dictating the direction of the research in a more theoretical manner and may have caused an inauthentic investigation into the STEM activity itself. As a result of these considerations, it was important to identify existing and authentic STEM activities to observe instead of designing and organizing them as part of the data collection strategy, even if this limited the number or variability of cases available for investigation.

The next limitation was the result of using of video cameras to collect data, which further limited the possibility of conducting research on very young children or within local schools without a lengthy ethical vetting process that would have detracted from the ability to collect data in a timely manner. Again, this limitation also encouraged this researcher to seek existing non-formal STEM activities that featured persons able to provide informed consent as participants. Activities taking place with the identified non-profit were therefore selected, which also implied the local national setting of Stockholm Sweden being selected as the overarching domain of the STEM context.

Considering more practical limitations, the breadth of data collected using digital video cameras also limits the volume of data that can be presented within such a limited timeline. Unlike other studies using ENA, specifically education-based studies within the LA or MMLA research fields, this study did not make use of automated transcription or coding processes. Therefore, this research project is limited to examining only the most significant portions of the total audiovisual recordings as part of the investigation. This may result in an incomplete overview of the STEM activity case contexts, and interfere in the holistic goal of informing learning theories into STEM. Furthermore, the application of QDA to only the latter stages of the data analysis, and therefore directed by the preceding results of the quantitative analysis and coding process, may imply missed findings from data that was not selected for transcription and coding.

Another limitation was identified within the analysis stage, and is the result of the dynamic nature of using the ENA webtool. When investigating the networks, it became increasingly obvious that still images of the networks could only communicate small portions of the findings at any one time. Using the webtool, it is possible to hover a cursor over nodes or edges and even manipulate the visuals of the networks to help in the analysis; however, this process is not accessible without sharing countless reiterations and alterations of each network plot. For this reason, it is possible that the static network visualizations may communicate more information to persons familiar with the ENA method than to those persons not familiar with it.

Finally, due to the 2020 lockdown because of the spread of COVID-19, the latter portion of the third STEM activity case cancelled. This resulted in incomplete data and for an important follow-up with the participants to not take place. More specifically, a data collection segment planned to collect multimodal focus group video data was not conducted. This focus group was meant to be a key element to the overall research project by providing an opportunity for the participants to reflect on taking part in the STEM activity by revisiting the tangible artefacts they interacted with or built over the course of the activity.

4.12 Ethical Considerations

Ethical considerations undertaken in the planning and implementation of this research project are presented here, insofar as these concerns shaped the methodological strategies employed, and the manner of interactions that took place between the researcher, the case organizations (non-profit and SDP), and the STEM activity participants. Also, it is difficult to avoid a more in-depth discussion about the ethical debates surrounding the personal or sensitive nature of video-based data, even when contrasted with otherwise anonymized methods for coding and analyzing such data. Lastly, the dilemmas faced by a researcher engaged in case-study design, where close relationships with stakeholders is developed over time, must be addressed to ensure transparency and confidence in how the findings of this research are presented.

The methodological decisions made over the course of this project, with respect to data generation, collection, storage, analysis, and presentation, were conducted in accordance to the guidelines presented under the European Union's General Data Protection Regulation (GDPR) released in 2016. A key point of dispute regarding the implications of newly released GDPR regulations has been the interpretation of the very nature of video source data and about the distinction between sensitive personal data and personal data. For example, modern Internet of Things (IoT) monitoring and network systems alongside AI processing algorithms create concerns regarding how data is generated with or without direct human knowledge and involvement (Antoniou & Andreou, 2019; Raab, 2020). This is relevant to the generation, processing, and storage of video source data, which can be processed in a manner originally unintended making it transcend the boundary between personal and sensitive data. Facial recognition software is a primary example of how video data can be biometrically processed in a manner that stretches the material from personal to sensitive.

As this research applies new analytical tools to video data, it is possible that future tools are developed that can extract even more information from the moving images. However, ensuring honest and transparent disclosure of research practice with participants via detailed consent forms can alleviate the concerns with using video equipment in research (Peters et al., 2020). The research participants were given detailed information about the nature of the research and the use of the video equipment in the form of consent forms and information brochures—the latter of which they could take with them and which included contact information should future questions or concerns arise.

One of the bigger debates regarding the use of video equipment in educational settings centers on whether or not this research is compromised if conducted on vulnerable populations (i.e., children). These debates are often complicated by various interpretations of how research using video cameras can be conducted, if at all, with children. For example, these debates stress that children have a limited ability to consent to participating in research, and lack even less awareness or understanding about the complexity of privacy compromises in the use of video in research (Rutanen et al., 2018). Regardless of this research project not recruiting participants under the age of 18, it is still possible that the implications and complexity of capturing participant interactions and visual representations in video format can sometimes be difficult to fully grasp even for adults. This research project was not subjected to ethical vetting and so was carefully conducted to ensure no persons under the age of 18 would be present, and that participants could only take part in video data collection after providing informed consent based on very explicit written and verbal explanations of data collection and data management strategies.

Despite the uncertainties about the future of video data use, ethical vetting was not conducted for two important reasons: 1) the data was collected anonymously and 2) no sensitive data was being extracted from the video source data to be included in the analysis. For these two reasons, the ethical integrity of this project is assured despite the use of moving images as source data. For example, the transcription process included redactions in the event names or other sensitive information was mentioned. As stated earlier, all participants provided signed consent forms prior to the collection of data, and information brochures about the project were provided. The brochures included information about the research project and the data collection and management strategy, in addition to informing the participants about their legal rights as research subjects.

5. Presentation of Findings: STEM Activity Networks and Uncovering Case Constructs

The goal of this investigation is to conduct two levels of analysis on the conversations and interactions taking place between the participants and how these reflect a relational structure between STEM subject knowledge and the 4C's outlined in the 21st century skills framework described earlier. The first level of analysis is a quantitative interpretation of the network plots generated by the ENA webtool, which includes statistical tests of significance between various relationship within the networks. The second level of analysis uses the Data View feature of the ENA webtool to revisit the interactional data that is associated with significant or otherwise intriguing relational cooccurrences in the networks. This second level of analysis is qualitative in nature and allows for deeper interpretations of relationships in the networks and how they can reflect on STEM learning theories or other opportunities for participants to communicate knowledge or display any of the 4C's. This combined analysis seeks to provide a more holistic and intelligible understanding of what was taking place within the STEM activity cases to inform how pedagogical theories about STEM learning can be more meaningfully associated with possible learning outcomes.

This mixed-methods approach can best address the sorts of research questions about how interactions between people, artifacts, the environment, and learning epistemics can shed light on how the learning of both subject matter and 21st century skills can be accomplished within STEM activities like the ones explored here. However, the findings from this examination yield more than information about how epistemics that represent STEM subject knowledge and 21st century skills manifest in network models. In addition to the network plots, the interpretative findings outlined in this section also bring to light constructs within the cases that serve to expand on the theoretical anatomical structure of the cases by uncovering additional contextual aspects to the cases that are only generated by the actions of the participants. Arguably, these enacted behaviors or utterances may be predicted to take place prior to observing the STEM activities; however, in order to include these contextual elements in an analysis of STEM learning within these cases, they must first be empirically documented rather than theoretically deduced.

Prior to collecting data on the selected cases of this study, a number of expected outcomes and patterns where anticipated to materialize within the analysis. One set of findings from the analysis reflect agreement with various claims about STEM learning and STEM activities presented in prior research and the body of academic knowledge on the subject of STEM education. For example, all three of the cases revealed that mathematics manifested the least within the epistemic coding of the activity data, and it was also mathematics that was linked the least with the other STEM subject knowledge epistemics—this is especially true in the third case study. On the other hand, the data analysis also uncovered information that inspires critical evaluation of some claims made about the advantages of STEM for learning the targeted subject matter, such as the case for how a community of practice can manifest communicative techniques focused more of efficiency rather than a true articulation and display of subject-based knowledge or expertise. Furthermore, following the analysis there were also a number of outcomes that proved more compelling than was originally considered when bearing in mind the general frameworks for designing STEM learning activities. As a result of these peculiarities of the STEM activity cases, some aspects of the cases require more discussion to determine their contribution to STEM learning in more generalizable terms. These include the element of using engineering students as mentors, the way that the STEM activities resembled maker kits, and the inclusion of a workbook into the latter two cases.

5.1 Taxonomy of the STEM Activity Cases

Each of the three cases provided documentation of what was said and done within each sub-group of STEM activity participants. This data was analyzed using an ENA webtool that generated network plots representing the various units of analysis and the epistemic codes used to classify the conversational/interactional data. The plots presented below represent the network as constructed by the rates of cooccurrence between the epistemics for each participant and for each key segment of the whole STEM activity.

The key features of the network plots that are discussed here include an interpretation of the analytical space (i.e., the epistemic frame of the activity). This is done by highlighting the analytical space as divided into four quadrants split between the horizontal and vertical axes. How the coded epistemics are located in relation to each other within these quadrants allows for an understanding of how each of the network models can provide information about patterns of cooccurrences that take place among the various units of analysis. This results in a dynamic space that can feature or hide various networks based on the selection of some or all of the units of analysis that are mapped according to the epistemic codes. These key features serve to identify a taxonomy and structure to the STEM activity cases based on the conversations and interactions that were displayed or uttered by the participants. In a subsequent analysis, each participant's contribution to the network is also examined.

In order to better understand how to interpret the analytical space and the plotted points within it, the diagram below clarifies the visualization of the data contingency tables as quantifiable measures of how they are related and situated within the analytical space. The nodes of the networks are situated on either side of the two axes, which can be considered as the dividing lines between high and low values of cooccurrences based on a standard understanding of grid-based coordinate diagrams (see Figure 9).

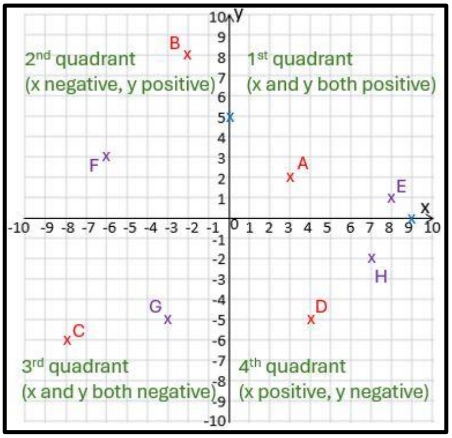

Figure 9: Grid-Based Coordinate Diagram
Creator: Lynne Davis, B28 Maths Tutor, 15 September 2024

For example, the upper right quadrant shows relative values for nodes that score higher on the X and Y dimensions, while the lower left quadrant shows relative values for nodes that score lower on the X and Y dimensions. The concept that is related to each of the two dimensions is determined by an overall examination of the network plot and the thematic codes underlying the analysis. The ENA webtool presents a comparison plot to showcase the overall network, which requires that at least one network is selected to be represented in order to see the epistemic nodes within the plot. Also, the nodes that are presented in the network plot are either small circles, which are various nodes for one or more units of analysis, and the larger square nodes, which indicate network centroids and the mean weighted location of the network connections for the main units of comparison—the main units of comparison for much of the analysis are the STEM activity participants. The dotted lines in the shape of a square surrounding each corresponding-colored network centroid represent the estimated confidence interval (CI) for that network.

When examining the location of the nodes within the plots it is possible to interpret underlying similarities with how connections are made between the epistemics for each subject of the network/unit of analysis. For example, if two nodes are located close to each other and within the same quadrant, this indicates that each of those node, and whatever construct they represent, presented similar patterns of association among the epistemic codes. This does not imply that they are necessarily related to each other, but is does suggest that whatever concept they represent is discussed or enacted by the participants in a manner similar to each other or are temporally related. This can imply that the same words or actions that are coded according to the epistemic frames are enacted or spoken within the context of whatever the node itself represents.

An important distinction to keep in mind is that when nodes are positioned closer to each other this does not suggest that these nodes cooccur together more frequently in and of themselves. Rather, what this pattern communicates is that these nodes share similar patterns of cooccurrence among all of the coded epistemics throughout the entire activity. What this suggests for nodes that are located closer together, and especially within the same quadrant of the analytical space, is that the constructs or unit of analysis that these nodes represent share comparatively more similar patterns of cooccurrences among the coded epistemics when compared to other nodes situated further away or within other quadrants. In the analysis of the overall cases below, this examination is done based on how the coded epistemics themselves are situated within the analytical space and how each of the various data segmentations of the cases contribute to how these epistemics are positioned.

5.1.1 Case One: Engineering Student Hackathon

When looking at the locations of the various epistemics within the analytical space, it is possible to denote a general taxonomical description of the activity in relation to the cooccurrences between STEM subject knowledge and 21st century skills. For example, the STEM epistemics are mostly located closer together when compared to the 21st century skills epistemics and are mostly situated within the lower right quadrant of the space. This suggests that there is a stronger cooccurrence of STEM subject knowledge within the discussions and actions of the participants than there is among the 21st century skills. The more dispersed locations of the 21st century skills epistemics reveals a pattern of association less so with each other, and requires deeper analysis of the individual nodes that comprise of the connections to understand this trend.

For example, STEM.tech and STEM.eng are located in the same quadrant and relatively closer together, which suggests that coded indications of STEM technology and STEM engineering presented similar patterns of connections among all of the variables of the network activity. For this reason, it is plausible to anticipate that engineering and technology require similar skills and knowledge to discuss and enact. These two epistemics are more likely to represent ideas and discourse that are connected and located within the same stanza windows.

Another example can be the relative closeness between the TCS.crit, TCS.creat, and STEM.math epistemic nodes. This suggests that discussions or actions that included mathematics had similar patterns of association among the various units of analysis when compared to the sorts of discussions or actions that were coded to manifest during critical thinking and creativity. It is possible to review the data source to reveal that aspects of budget were often factors in the unusual design and functionality applied by the participants in this case. For example, the desire to not purchase expensive items like a second wheel or the light sensor (arguably essential components to building an electric vehicle model) resulted in the pursuit of very technical and unorthodox thinking such as hacking the Micro:bit to access the LED display's light sensing function.

Due to the dynamic and interactive nature of ENA, it is possible to select or isolate different units of analysis in response to patterns in the data that require more elaboration or that may require further explanation. For example, the unit of analysis that divided the activity into the various thematic sections was hidden from the network plot to simplify the model in order to better understand the locations of the STEM knowledge and 21st century skills epistemics. Furthermore, with a simplified network plot to examine, it is easier to identify the differences highlighted within the comparison plot showcased by the ENA webtool.

The simplified plot reveals more frequent connections in thinking and acting occurring between the STEM epistemics in addition to inclusions of the 21st century skills. On the other hand, the epistemics related to 21st century skills occurred less frequently together without the inclusion of additional STEM epistemics. This is represented by the STEM epistemics being more central to the network while the 21st century skills epistemics tend to be situated along the outer perimeter of the epistemic frame.

The case of the engineering student hackathon generated a plot that did not show many examples of significant differences between the networks related to each participant based on the locations and overlapping confidence intervals (CIs) surrounding each centroid. The exception to this trend can be seen by the centroid for the non-profit staff member that served as the activity mentor (in red), and the blue centroid for one of the participants identified as "s3" (i.e., "student three" based on seating arrangement). Based on the locations of the red and blue CIs, it is reasonable to suggest that the networks for these two participants are significantly different as regards the nature of the connections made between the epistemics for STEM subject knowledge and 21st century skills. Furthermore, it is revealed by the network model that participants that were working on the same thematic sections of the activity produced greater variation in their networks rather than less variation as would be expected based on the simple interpretation that they would be discussing the same topics and interacting with each other more frequently than participants working on other sections. For example, the CIs for s3 and s2 overlap so slightly that it is possible that these two participants, who both worked on the design and construction of the vehicle, have statistically significant differences in how they formed connections between the STEM and 21st century skills epistemics. These different patterns of connected ways of thinking and enacting 21st century skills were present despite these two individuals directly working together on the same section of the STEM activity and speaking more directly to each other than to the other STEM activity participants in their group.

The same general trend is visible when looking at the CIs for s5 and s4, who worked together on writing the code to control the vehicle model. The CI for s1, who was working individually on building the electronics for the vehicle is situated within a moderately middle point among all of the CIs. Generally speaking, the overlapping CIs identify participants in the STEM activity that produced utterances and interactions more similar in how they reflected the cooccurrence of STEM subject knowledge and 21st century skills. The trend in participants engaged in the same thematic section of the activity being the most different in how they form connections between the knowledge and skills epistemics is an interesting development, and may have implications for the design of collaborative groupwork activities that encourage learners to take on only portions of the overall activity.

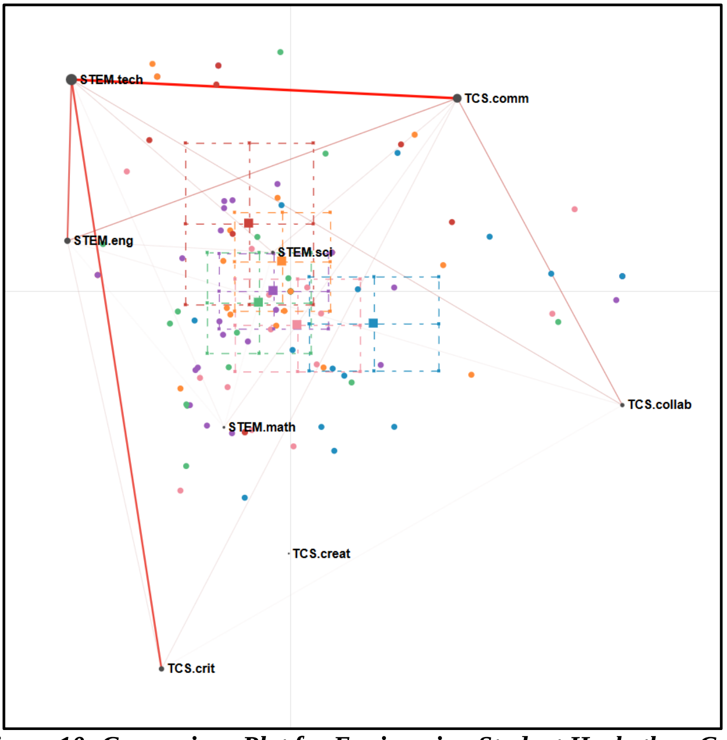

Figure 10: Comparison Plot for Engineering Student Hackathon Case Confidence Intervals (CIs) indicated by rectangles outlined with dotted lines.

5.1.2 Case Two: Mentor Training

The second STEM activity case produced data from two engineering students working together to build and program a vehicle controlled by light sensors—this activity was derived from the hackathon case discussed earlier. The participants had previously taken part in the Engineering Student Hackathon and were familiar with the activity, but were asked to complete the task as a form of training and preparation to serve as mentors for when the same activity would be undertaken by Swedish school teachers.

When looking at the overall network generated by the ENA webtool it is possible to identify that within each set of four epistemics, there is one epistemic situated further apart from where the remaining three thematically related epistemics tend to collect. For the STEM epistemics, all but the epistemic related to science are situated within the lower left quadrant of the analytical space. For the 21st century skills epistemics, all but the one related to critical thinking are located in the upper right quadrant.

The discussions and actions of the two mentors create a STEM activity structure that can be generally described as featuring stronger isolated cooccurrences between STEM epistemics and 21st century skills epistemics rather than an integrated combination of the two. However, critical thinking tends to cooccur with the STEM knowledge epistemics more than the other 21st century skills. Utterances or actions related to science concepts or topics tend to cooccur with the 21st century skills epistemics rather than with the other STEM epistemics. Furthermore, the epistemics of critical thinking and creativity are most strongly associated within the 21st century skills epistemic group, and the science epistemic cooccurs most strongly with technology within the discussions and actions of the mentor training activity.

When looking more closely at the individual nodes within the overall networks, it becomes clear that the largest influence on the connection of science to the other epistemics comes from the discussions and actions generated by the non-profit staff member that served as the instructor of the activity for the two mentors-in-training. When looking over the information provided by the Data View option within the ENA webtool, it becomes clear that the instructional comments made by the non-profit participant are the key instances of introducing scientific concepts into the activity, and the resulting epistemic frame.

When looking into the similar patterns of connections that are made overall within the activity, the most similar patterns would be between how discussions that reflect critical thinking (TCS.crit) are similar to how connections are made when the participants discussed or enacted coded manifestation of scientific concepts or practice (STEM.sci). This suggests an interesting association between the use of science in this case and how it may prompt or reflect the use of critical thinking. The fact that this second case study challenged the participants to understand more details of the entire activity than what was needed in the previous hackathon case, suggests that the participants were required to use more of their scientific and theoretical knowledge to address, or fully understand, complicated sections of the activity—e.g., understanding the differences between analog and digital signals.

The networks that were generated from the discussions and actions of the mentors tend to showcase similar patterns of cooccurrences with only minor distinctions in where some connections occur. The STEM activity case for the mentor training shows the greatest variation between the two mentors and the non-profit staff member serving as the instructional tutor within the context. However, the locations of the confidence intervals suggest that this difference is not statistically significant, which may reflect the shared engineering backgrounds between the non-profit staff and the engineering students. The general structure of the Mentor Training case is quite balanced with respect to how each participant may have contributed to the overall structure of how the activity unfolded based on the general clustering of nodes within the origin (i.e., center) of the analytical space.

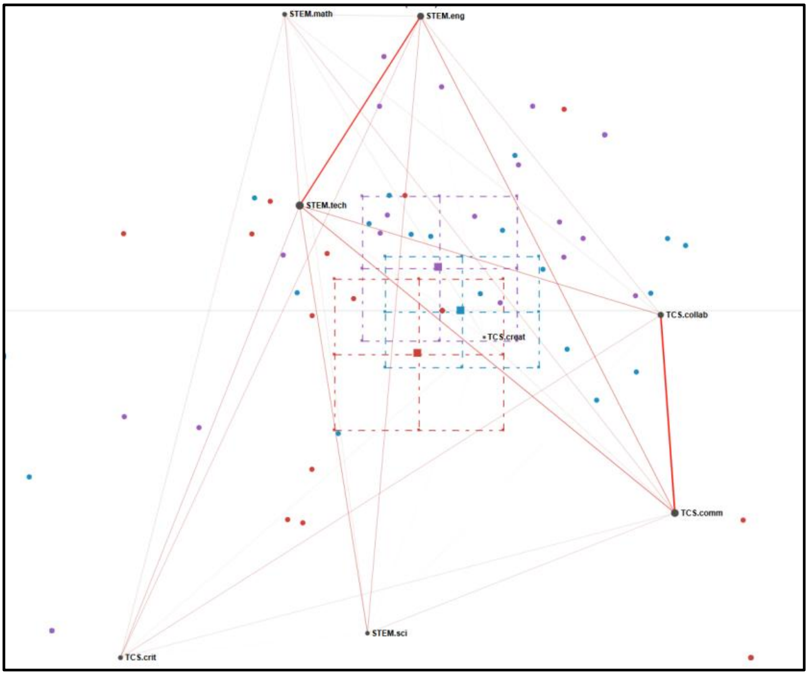

Figure 11: Comparison Plot for Mentor Training Case Confidence Intervals (CIs) outlined with dotted rectangles.

5.1.3 Case Three: SDP Teacher Workshop with Mentor

The third STEM activity case featured engineering students that participated in the previous STEM activities examined in this study serving as mentors instead of as direct participants. The participants in this final case, and the final iteration of the overall STEM activity organized by the non-profit, were Swedish school teachers that were intended to apply the design and materials of the STEM activity within their own classrooms. The structure of this case's network is a combination of the five secondary school teachers and the one engineering student mentor. This third STEM activity case features participants with the most varied backgrounds, knowledge, and skillsets when compared to the previous cases that featured only engineering students.

One pattern that is immediately apparent is the close proximity between the nodes TCS.crit and STEM.eng. This suggests that the patterns of connections that are made in this activity by the participants show similar cooccurrences when looking for the manifestations of engineering constructs and critical thinking constructs. This suggests that either these two epistemics were associated with the same conversations and actions that take place in the activity or that each epistemic features within the other's network. It is possible to look into the conversations of the participants to better understand this connection. From examining these conversations, it is possible to conclude that many of the challenges faced by the teacher participants were more technical in nature rather than theoretical in nature as was the case with the mentor training case. In other words, the teacher workshop case can be interpreted to show more desire to understand the successful functioning of the vehicle artefact, while the mentor training case is more associated with the participants looking to understand the scientific underpinnings behind why the artefacts function in particular ways.

The ENA webtool generated a network plot with the nodes dispersed away from the origin of the analytical space in a somewhat uniform manner within each of the four quadrants. The confidence internals and the centroids for each of the participant's networks reflects this scattering of the nodes. This results in a network with larger squares for the CIs, and with the centroids located predominantly near the origin and close to one another. The exception to this pattern of centroid locations is the centroid for the mentor of the activity, which is located furthest away from the teacher's centroids and is situated within the upper left quadrant of the dimensionally-reduced space (i.e., the analytical space).

The interpretation of the location for the mean-weighted centroid for the mentor is that the utterances and actions of this individual feature different connection between the STEM knowledge and 21st century skills epistemics to those produced by the teacher participants. Overall, the larger CIs suggest a greater amount of variation in how the connections between the various epistemics are created and requires a deeper investigation of the utterances and actions within the Data View field of the ENA webtool in order to establish meaning to this finding. The relatively smaller CI surrounding the centroid for the mentor of the activity suggests that there is a more consistent relationship with the connections made by the mentor, which are also more related to the STEM knowledge epistemics rather than the 21st century skills epistemics.

The particular roles of each of the participants is somewhat reflective of the locations of the network weight means, and points to the importance of the roles each of the participants undertook within the activity as shaping the sorts of connections their discussions and actions generated between the various epistemics. The ability to identify this trend was based on the segmentation of the data into stanzas for each of the specific topics of the activity, which were divided among the participants as a deliberate design of the STEM activity.

The locations of the epistemic codes and the epistemic frame they generate for interpreting the meaning behind the locations of the various network nodes present a similar pattern of relational strength among the epistemics of STEM subject knowledge and those of the 21st century skills category. A general pattern can be identified that places the STEM knowledge epistemics along the left upper and lower quadrants of the analytical space while the 21st century skills epistemic are generally situated within the right section of the space. The location of the critical thinking epistemic node within the left quadrant, and closer to the STEM epistemics, is the most notable deviation from this overall pattern in how the epistemics are placed with the network model. This finding may point to this 21st century skill being mostly applied when discussing the engineering and mathematical themes of the STEM activity.

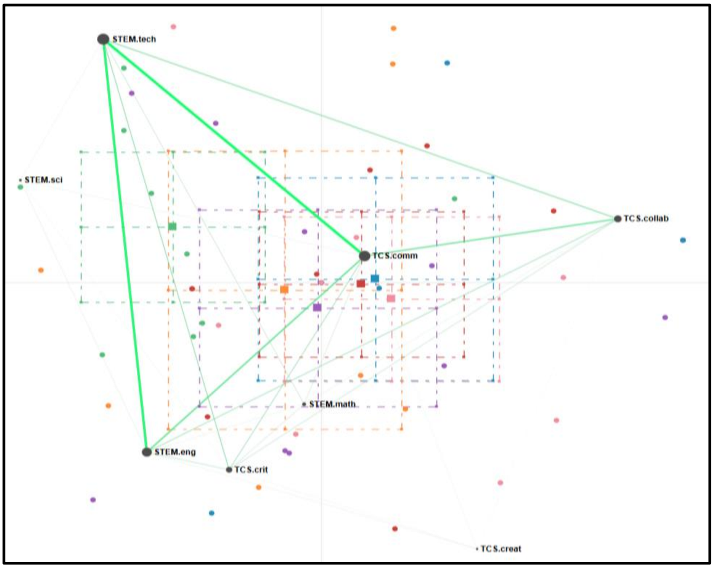

Figure 12: Comparison Plot for the SDP teacher Workshop Case Confidence Intervals (CIs) outlined with dotted rectangles.

5.2 Frames, Stanzas, and Networks for Case Participants

The findings of this research project also serve to demonstrate how the STEM activities examined here present conversational or visual information that can be used to discuss if and how these cases align with, or deviated from, existing research and discussions on STEM learning. This discussion blends qualitative and quantitative findings that represent multimodal interactions (talk and gestures) that signify the manifestation of constructs such as STEM subject knowledge or the application of 21st century skills. This manifestation of constructs is presented within relational patterns of cooccurrence and how these relations may develop between them.

The STEM activities examined in this study become shaped and understood based on the actions and conversations of the participants, rather than described based on general theoretical models of STEM education and learning. Therefore, it is interesting to determine the nature or conditions of STEM learning based on how the learning context is shaped by the processes amongst the activity participants, and how this may or not reflect standard assumptions of how a general STEM activity unfolds and provides learning opportunities. This examination of the findings also stresses the stanza-based segmentations of the STEM activity into various role-based or task-based thematic sections.

The overarching aim of this study is to identify and examine the processes taking place over the course of STEM activities within the context of multiple case studies that are represented by unique analytical models in the form of epistemic networks. These network models capture the specific relationships between various units of analysis and coded epistemic constructs related to STEM knowledge and 21st century skills that can be identified and mapped within each of the cases. Simply put, each case is meant to be visualized and represented in a complex model referred to as an epistemic frame onto which the various network models of each participant are projected in order to provide evidence for a data-driven understanding of STEM learning.

This particular method of data analysis provides not only a rich data-based description about what is taking place in each STEM activity, but also allows for inter- and intra-case comparisons that can be utilized in formulating the pivotal discussion about STEM and how it contributes to subject knowledge and modern skills development. Furthermore, this method also permits the units of analysis within each case to be isolated, and to draw a deeper and hopefully thicker description of what is taking place within the activities as a result of the individual contributions and ways of thinking of each participant.

One exploration of various units of analysis targets interactions between individuals and artefacts existing or created within the scope of the activities. Another approach is to compare network plots generated from the data to compare units of analysis such as persons, groups, and even the workbook incorporated into the mentor training case and the SDP teacher case.

The following discussion is organized into sections that present findings from the data analysis that either confirm or refute existing research claims about the positive or negative impacts that generalized STEM learning and STEM activities have on the learning and application of subject knowledge and opportunities to use and refine 21st century skills. First, data that aligns with claims about STEM learning and STEM activities that are either encouraging or cautionary about the contributions of this subject matter is discussed. Next, data that deviates from the findings of previous research or allegorical claims about the advantages or disadvantages of STEM learning or STEM activities is presented.

The following discussion also presents the ENA analysis for each activity when the units of analysis are kept consistent between the cases and focuses on representing the cases by relational conditions between STEM subject knowledge and the practice of 21st century skills. One of the limitations of using the ENA webtool is that the plots are complex and best viewed in a dynamic manner. However, each of the relevant plots will be represented according the overall network with the epistemic frame, and with further detailed network plots for each of the units of analysis.

It is important to keep in mind that each of the three STEM activity cases were analyzed within the ENA webtool as separate projects, and so the analytical space presented by each set of ENA plots cannot be compared visually to the other cases despite unit comparisons being accessible within each case.

The network plots are constructed based on the epistemic codes, the conversation or interaction data transcriptions, and specified units of analysis that offer points of comparison within the case-specific analytical space. For each case the units of analysis are different but generally isolate for individual participants and/or segments of the STEM activity. For all of the cases the conversational data is based on the utterances made by the participants and some key nonverbal aspects of communication that are reflective of the epistemic codes. The epistemic codes are divided into the four subjects of STEM and the 4C's of 21st century skills.

5.2.1 Case One: Engineering Student Hackathon

The first case was a hackathon with engineering students. This case aims to help understand the STEM activity case within the higher education context with respect to the community of practice (CoP) of the engineering students who have a greater amount of expertise on the STEM subject matter present in this case. In light of the participants being expected to present relatively greater expertise of STEM concepts, it is important within the scope of this research project to understand how this subject knowledge is shared and manifested within the interactional dynamics of the group when solving the problems of the activity. The overall CoP is a combination of the networks for each of the participants and the particular theme of the activity they were responsible for addressing, which is why the individual networks may not all be identical despite being framed within the same analytical space. Furthermore, one of the arguments for the use of STEM activities within higher education, in particular engineering education, is that it allows for an opportunity for practicing 21st century skills when solving complex problems within a group context, which is more indicative of how engineering practice is conducted in industry contexts.

The group of students observed during the engineering student hackathon case divided themselves into three subgroups to address the different aspects of the activity: one participant (s1) built the electronics; two participants (s2 and s3) designed and built the body of the vehicle; and two participants (s4 and s5) wrote the code to control the vehicle according to the task requirements. When looking to understand how each of the participants contribute to the overall network of the STEM activity, their individual utterances and actions in response to their environment and group members generate network models that reflect their contribution within the bounds of their specified subgroup.

Despite working on the same tasks, it is interesting to note that the networks for s2 and s3 have centroids and confidence intervals located almost in isolation from one another with only a slight overlapping of the CIs along one of the edges on the X-axis. When running a parametric two sample t test for these two networks, it is found that there is a statistically significant difference between the networks of s2 and s3, but only along the X-axis whereas no significant difference is found between these networks along the Y-axis.

The network for s3 was found to be different from the networks of the non-profit instructor/mentor, s1, and s4 as well. These differences were calculated as statistically significant along the X-axis for s1, s2, and s4, and along the Y-axis as well when compared to the non-profit. The participant s3 produced utterances and actions that connected to the STEM and 21st century skills epistemics in a way most unlike those performed by the other participants. When looking over the Data View information in the ENA webtool, the limited participation in general of s3 (e.g., spoke very little and made very few specific references to STEM knowledge) may be one factor in the deviation of this network from those of the other participants. When looking at the network plots and the edges of the network in particular, there are stronger links between STEM epistemics for s2 and stronger links between the 21st century skills for s3.

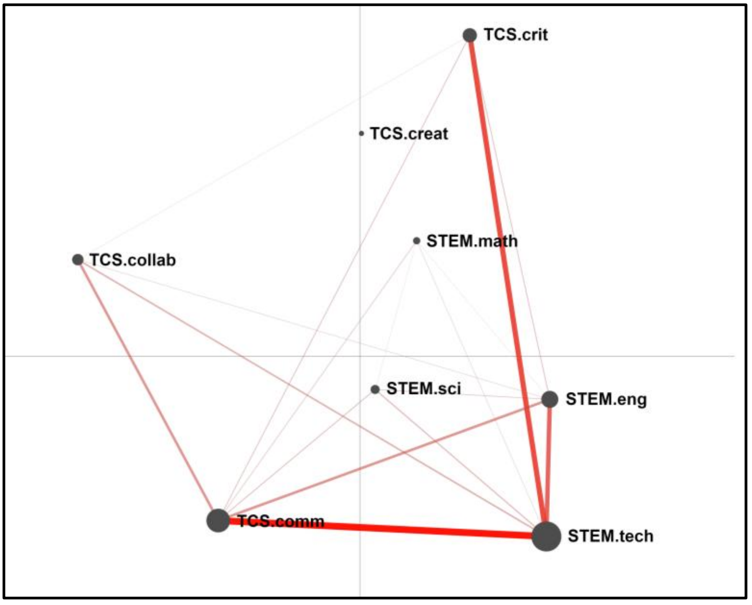

Figure 13: Network Plot for Non-Profit Staff (i)

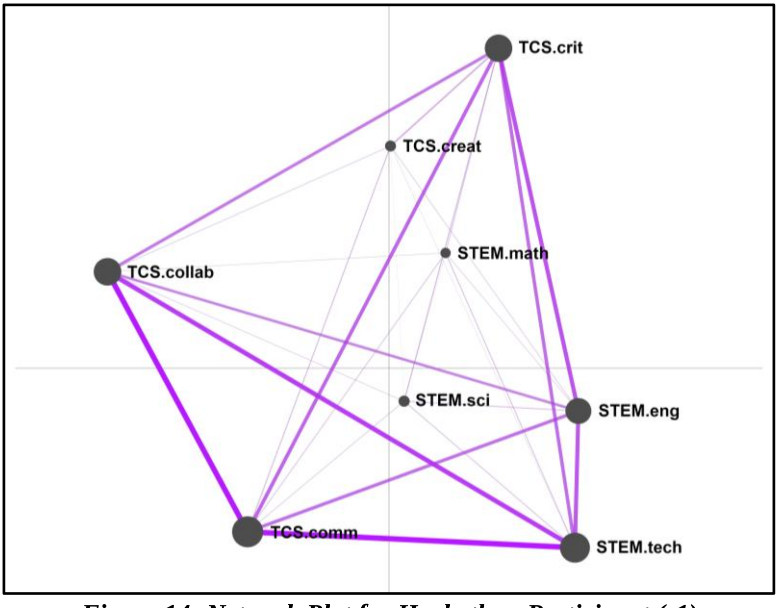

Figure 14: Network Plot for Hackathon Participant (s1)

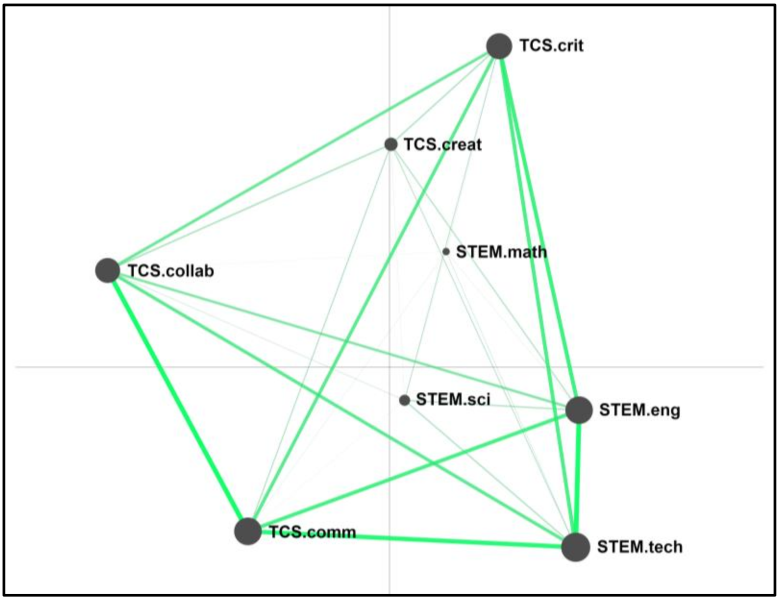

Figure 15: Network Plot for Hackathon Participant (s2)

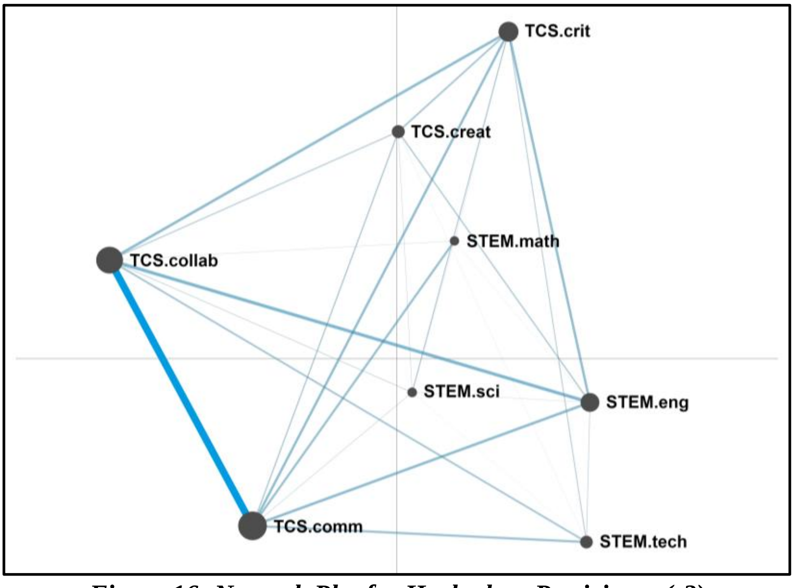

Figure 16: Network Plot for Hackathon Participant (s3)

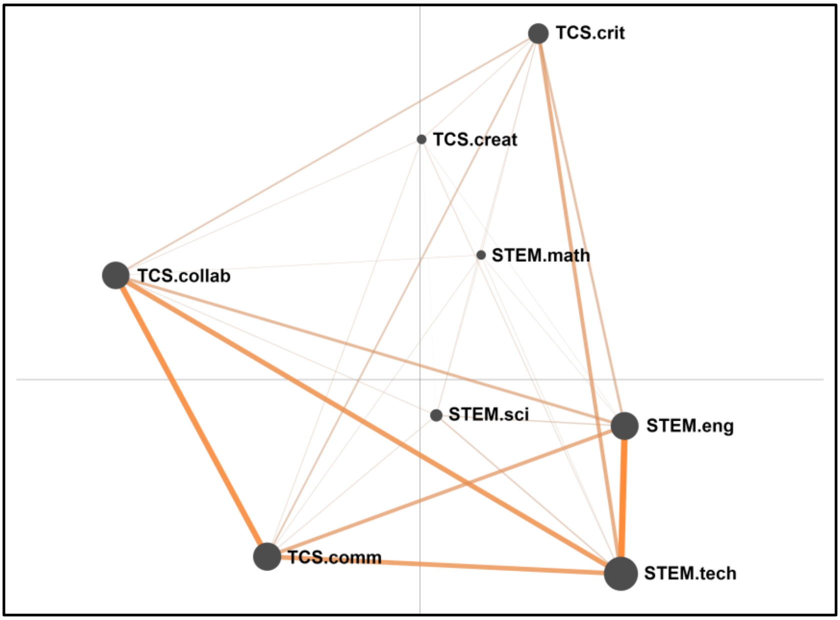

Figure 17: Network Plot for Hackathon Participant (s4)

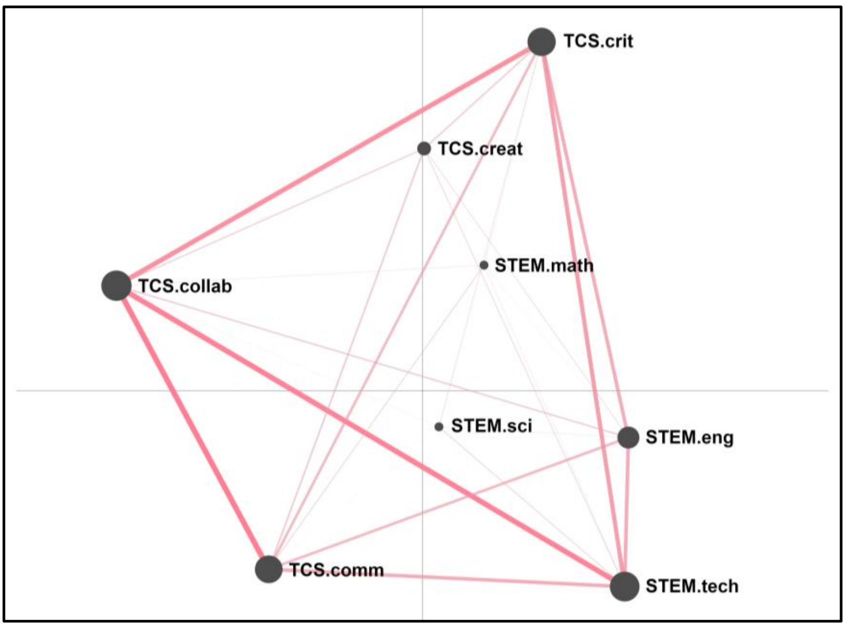

Figure 18: Network Plot for Hackathon Participant (s5)

The general trends for the participants of the engineering hackathon case, as indicated by their network plots, suggests that the most varied connections made between the STEM and 21st century skills epistemics occurred between participants taking part in the same themed sections of the activity, and that the mentor/instructor produced a network most varied to the other participants. The greatest significant differences were indicated along the X-axis, which suggests that the greatest variation in the conversations of the participants was in how they reflected either STEM or 21st century skills rather than connections between these two concepts.

5.2.2 Case Two: Mentor Training

The second case is outlined in detail in the methodology section but can be briefly described as featuring two engineering students working together to follow instructions provided in a workbook to build and program and electric vehicle. This activity was meant to prepare the students to serve as mentors for when this activity would be delivered to Swedish teachers. The ENA webtool was used to isolate the individual networks for each of the two engineering students (identified as 1esm and 2esm) and to also reveal the overall epistemic frame generated by their conversation and interactions over the course of the activity. There was also a third contributing speaker (a non-profit staff organizer) that was present and contributed to the overall epistemic frame, but which is not included in this ENA analysis. The activity itself is divided into four main segments based on the key elements of the activity. These four segments are: PREP (preparations before the activity begins and reading the workbook); ELECTRONICS (putting together the electrical components and addressing any associated questions within the workbook; MICRO:BIT (writing and testing the code); and VEHICLE (putting all of the components together to produce the final product).

As a result of the transcription and coding processes, the data was also segmented according to the following activities: introduction and instructions; reading of the booklet; asking questions; providing answers; tinkering; planning; social utterances; building; testing; problem solving; experimenting; coding; and designing. These segments were determined by applying a QDA method of reviewing the data and identifying clear categories of activity, and by the key segments of the mentor training workbook. All of these variables were taken as possible units of analysis within the ENA webtool and were used to construct the network plots together with the transcription and epistemic codes. Figure 19 features an image of the webtool window displaying the networks for 1esm (blue, top right) and 2esm (bottom right) in addition to the overall network situated on the analytical space in the center of the image.

The network model generated by the ENA webtool is a comparison plot featuring primarily only the two mentor participants who are identified as “1esm” and “2esm”. The simplicity of having only two primary units of analysis allows for the comparison plot to highlight edges within the network that represent the most varied trends in the epistemic cooccurrences between the participants. This is done in the ENA webtool by removing all of the identical network connections, which results in highlighting only those that are unique or more frequently occurring from only one participant. The comparison plot reveals that the most prominent difference in the networks of the two mentors is the weight of the connections made by 2esm between the STEM epistemics of technology and engineering and their cooccurrence with the 21st century skills epistemic of collaboration.

The other notable difference between the two mentors is that 1esm showcased more weighted connections between the 21st century skills epistemics of communication and collaboration. A very general statement can be made that suggests 2esm engaged in the STEM activity in a manner that generated more discussion and actions related to collaboration with the technological and engineering aspects of the activity. On the other hand, 1esm engaged in the STEM activity in a manner that demonstrated more communicative and collaborative utterances and enactments. Despite these differences between the networks of the two mentors, the locations of their respective confidence intervals suggests that any differences between these two mentors are not statistically significant. By and large, the two mentors display similar actions and conversations within the context of the STEM activity in terms of how they form connections in their ways of thinking and acting within a collaborative STEM activity.

The general pattern in the connections made by the Mentor Training case features very little variations between the two participants with respect to how they each discussed the activity as it was unfolding. Also, the connections between the STEM knowledge and 21st century skills epistemics were more complex and stronger then when compared to the other two cases. When subjected to interpretation, the increased complexity of the connections made in this case (when compared to the other two) may reflect the increased familiarly of the project on the part of the mentors-in-training after having completed the activity once before. Furthermore, this comparatively complex network can be based on the simple fact that the participants are members of an engineering CoP that, to some degree, could be more advanced than within the other cases, and that the self-selection of becoming mentors may already suggest some increased proficiency in practicing 21st century skills.

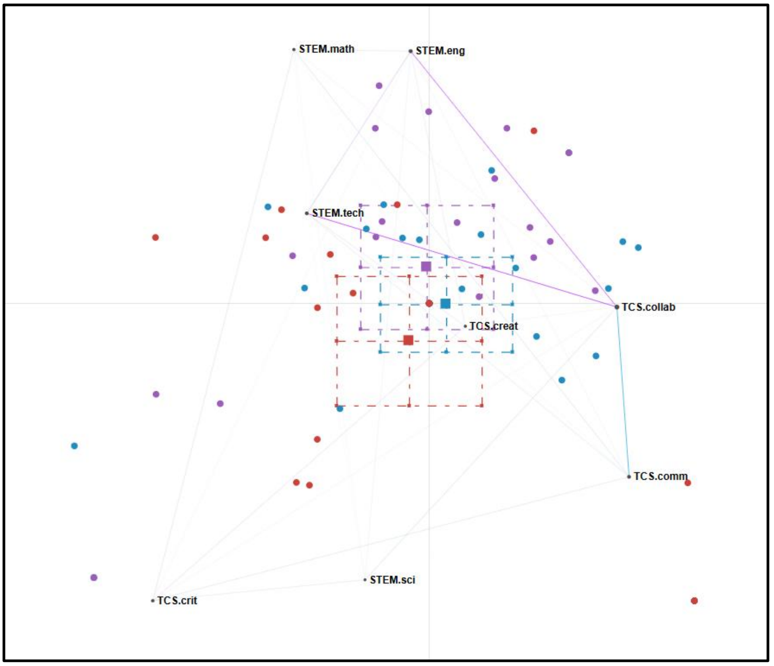

Figure 19: Combined Network Plot for 1esm and 2esm Overlapping connections removed to highlight distinct cooccurrence patterns between the two participants.

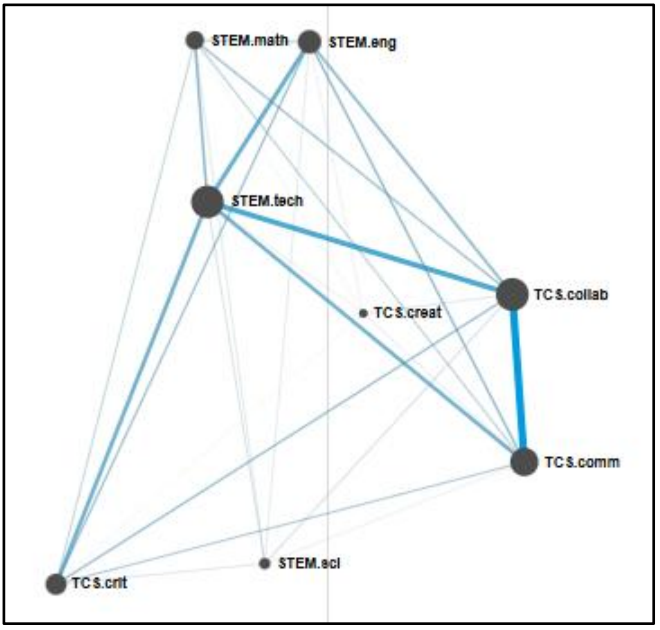

Figure 20: Network Plot for Engineering Student Mentor 1 (1esm)

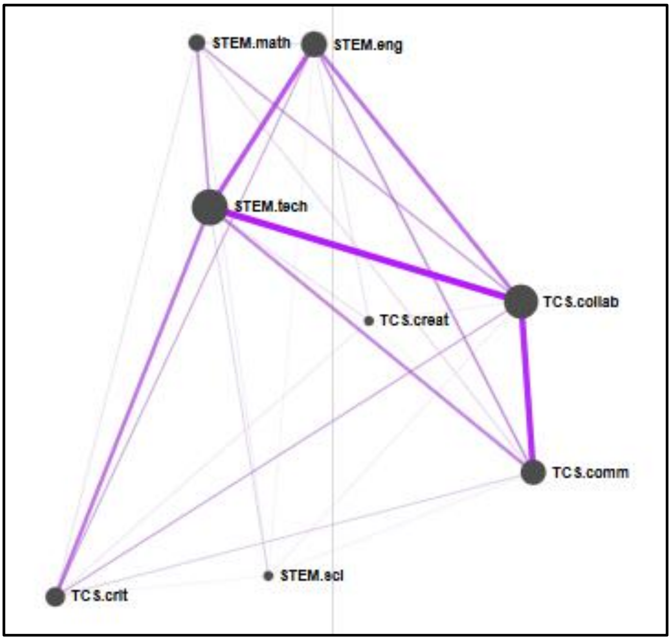

Figure 21: Network Plot for Engineering Student Mentor 2 (2esm)

5.2.3 Case Three: SDP Teacher Workshop with Mentor

The final STEM case was the school development program (SDP) Teacher Workshop, which featured Swedish teachers as the participants and one engineering student serving as their mentor for the activity. The subcase was one group of teachers that agreed to communicate with the non-Swedish speaking mentor, and each other, using English. The five teachers divided themselves into three subgroups based on the sections of the activity they would tackle. One teacher was the project manager (s3), two teachers (s1 and s2) worked as the "mechanics" that designed and built the car and its electronic components, and two teachers (s4 and s5) worked on writing the code to control the vehicle. The engineering student (m) served as their mentor.

When looking at the centroids for the teachers, there is an apparent clustering along the line of the X-axis, which denotes less variation along the Y-axis for the teachers. When looking at the statistical comparisons using a two-sample t test, there is no significant difference on either the X-axis or Y-axis between how the teachers formed connections between the various coded epistemics based on their actions and conversations.

The mentor generated a network that is situated the furthest from the locations of the centroids for the teachers and was found to be significantly different along the X-axis to all of the teachers with the exception of s2. When looking over the comparison plots for each of the teachers and the mentor, the strongest weighted connections that served to place the network for the mentor within the upper left quadrant of the analytical space were the connections made between the STEM epistemics. On the other hand, the teacher networks were generally situated within the lower right quadrant, showing less strength in STEM cooccurrences when compared to the mentor. This implies that the utterances and actions of the mentor reflected more indications of knowledge about technology and engineering than those made by the teachers. Also, the mentor was not actively taking part in the activity and so was not so heavily engaged in interactions or utterances that could be identified within the 21st century skills epistemic codes.

When looking closer at the individual networks for the teachers, a pattern emerges that places the greatest relative distance between the two teachers involved in the electronics and design of the vehicle (s1 and s2). This section of the activity was shared by these two participants. When looking at the Data View for the conversations and actions taking place between the two participants, there was a confirmation that one teacher took on the more technical task of building the electronics and so produced more connections with the STEM epistemics when compared to the teacher that worked on the design aspects of the task, which then results in more connections along the edges between 21st century skills such as communication and collaboration. This division of labor may place the two teachers into separate domains, where one focuses on design aspects of the activity and the other focuses only on the technical, electronic, components. This subdivision produced different networks because the skills and knowledge required for each one may be different with respect to the application of either STEM knowledge or 21st century skills enactments.

The two teachers that worked on the coding of the vehicle (s4 and s5), also presented a similar pattern of discrepancy, with one teacher creating more relatively stronger connections between the STEM epistemics when compared to those made by their teammate. Again, the Data View reveals that the participant with more STEM epistemic connections (s5) was more vocal about the technical aspects of the coding and how the coding was connected to the function of the electronic and mechanical parts of the vehicle.

The teacher that served as the project leader (s3) was situated within the middle of the cluster of centroids for the teachers, which may have been associated to how this participant worked to communicate between the two subgroups of teachers working on different aspects of the activity. Also, this teacher participant showed the most direct connections to the mathematics epistemic when compared to the other participants, which reflects the focus on the budget that the role of the project leader specified. The other participants either did not connect to the mathematics epistemic, or did so only through connections made via another epistemic such as engineering. The only other participant that showed connections to the mathematics epistemic was s5, who was the participant that would engage with discussions about budget with s3.

The general trends with the networks for the SDP Teacher Workshop case show that the teachers had more similar patterns of connections between the epistemics when compared to each other, and that the teachers tended to show more variation in these connections when compared to the engineering student serving as the mentor. As in the first case of the Engineering Student Hackathon, the specific sections that each of the participants were assigned to did not result in less variation in their conversations and actions when compared to their teammates.

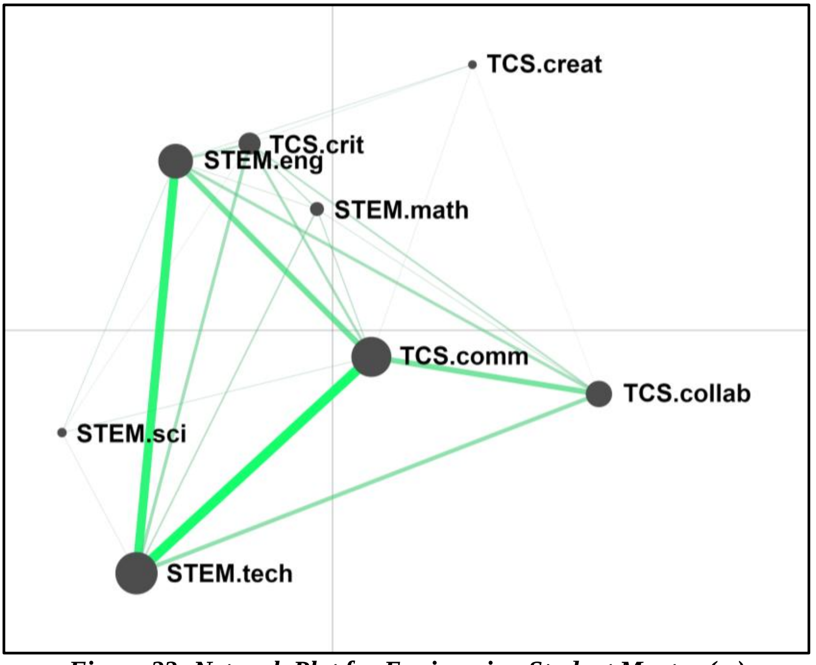

Figure 22: Network Plot for Engineering Student Mentor (m)

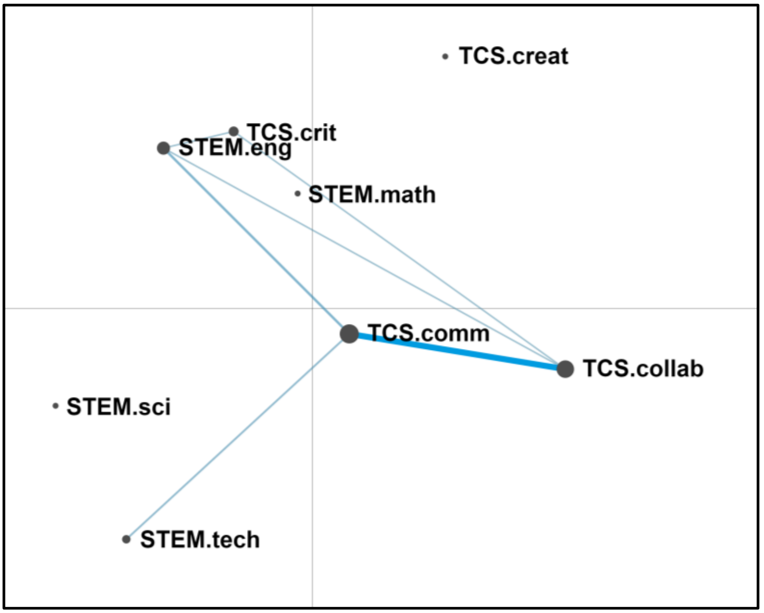

Figure 23: Network Plot for Teacher Participant (s1)

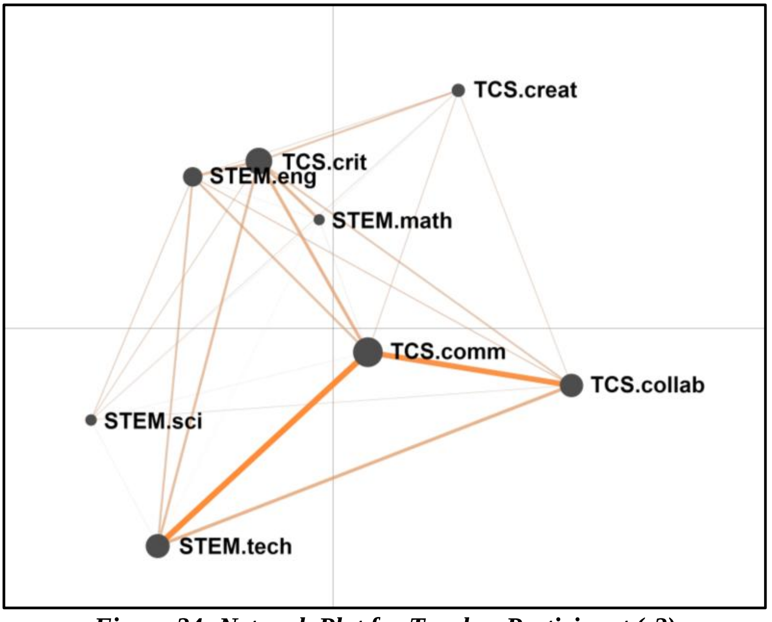

Figure 24: Network Plot for Teacher Participant (s2)

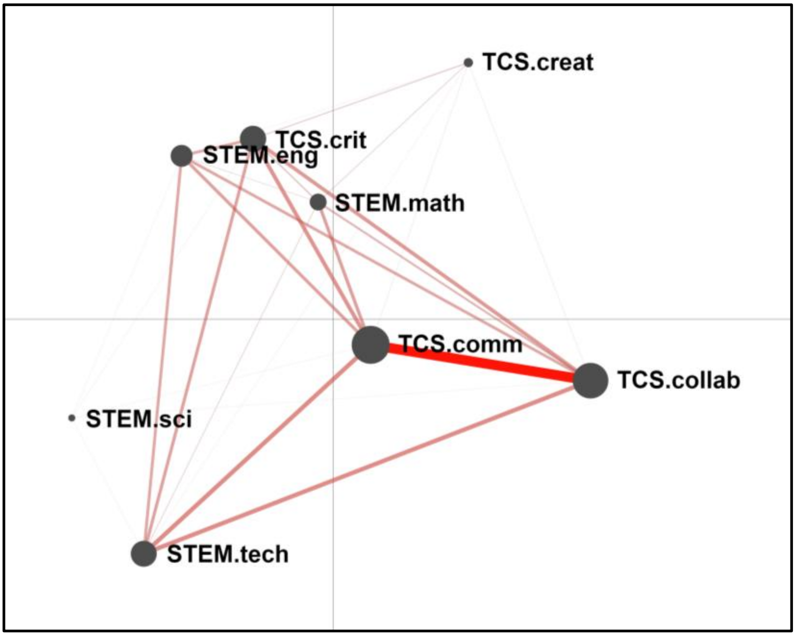

Figure 25: Network Plot for Teacher Participant (s3)

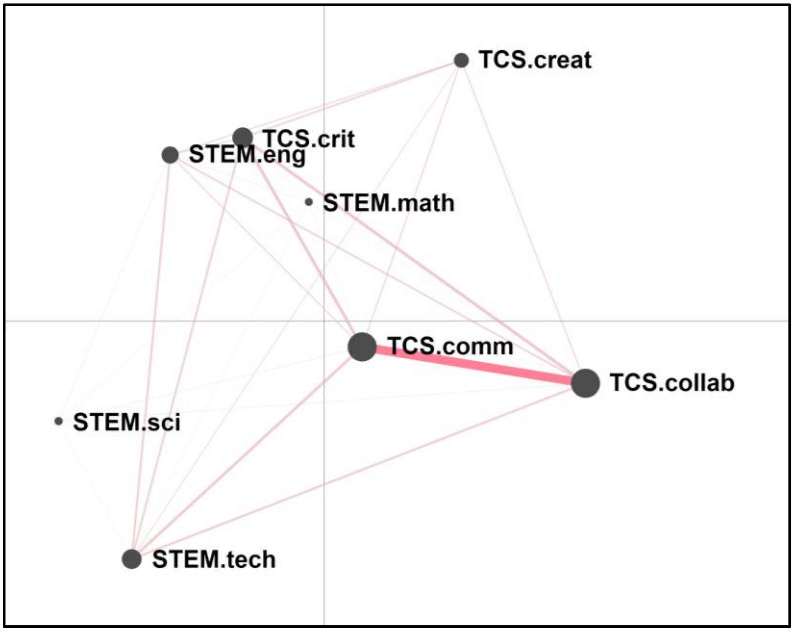

Figure 26: Network Plot for Teacher Participant (s4)

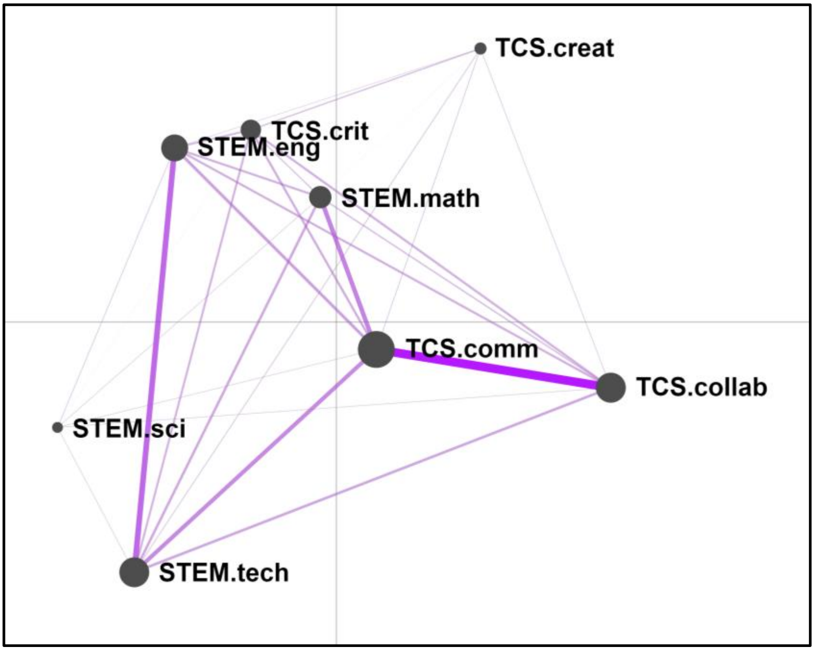

Figure 27: Network Plot for Teacher Participant (s5)

5.3 Workbooks as STEM Activity Artefacts: Symbolic Interaction and Shared Ontology

The decision to explore STEM activities came with some theoretical expectations about what could be found within the environment with respect to designing active and project-based conditions for learning. Again, these expectations could only be theoretical prior to data collection because the activity cases were not designed within the scope of this research project because they were pre-existing, authentic, non-formal STEM activities. However, these theoretical presumptions about what abstract conditions are engineered within STEM learning environments came with little preconceived expectations about the actual content of the activities or the materials that would be present as either tinker artefacts or learning artefacts for the participants to interact with.

In the cases explored in this research project, one element of the learning environment that proved interesting was a workbook provided to the teachers and mentors to presumably assist in the activity in some manner. Such workbooks are not always present in formal or non-formal STEM education or activities, and yet was present for the latter two iterations of the overarching electric vehicle STEM activity context.

One of the main components of the STEM activities examined in this research project turned out to be the workbook developed by the non-profit organizers in order to assist the participants with instructions, information, and exercises about the various challenges and knowledge that were incorporated into the electric vehicle activity. The non-profit team did not formally plan the workbook from a pedagogical perspective, but it is possible to interpret it as such to determine if or how the workbook served a useful purpose in the mentor training or teacher workshop. It should be noted that the workbook was written entirely in English and although this may have interesting implications for understanding the artefact within this learning environment, that is not one of the aspects of this research, and will therefore not be addressed in more detail.

The workbook is described in written detail because the actual reproduction of its contents may violate trust and copyright privileges between the non-profit team and the principal investigator responsible for this research.

Figure 28: Example of Maker Kit / Tinker Box Featuring materials, instructions, and activity workbook.

Without getting bogged down in a potentially rich semantic discussion about the word "workbook", it is important to distinguish the nature of this workbook from possible confusion with terms like textbook, exercise book, activity book, or even manual—however, it is unclear if this term was selected by the non-profit organizers deliberately or not. The idea often associated with "textbook" is that of written and pictorial learning supplements that are intended to be read by students to provide information, facts, and explanations about subject-based content. The workbook used in these STEM activities presents similarities with learning resources such as a textbook.

When exploring the nature of the workbook used in the Mentor Training and SDP Workshop cases, it is possible to draw better comparison with the sorts of workbook/activity books provided in consumer products such as tinker boxes, inventor kits, STEM crates, etc. (see Figure 28).

The inclusion of a workbook by the non-profit organizers of the STEM activity cases encourages consideration of the value of such materials within the context of learning theories about formal, non-formal, and informal STEM learning. In the case of consumer STEM products that are intended for use in the home, the workbooks tend to be needed for guidance, information, and explanations of key learning outcomes and themes because parents are intended to interact with the child and the STEM box in the absence of a formal educator or other possible learning materials.

The workbook, entitled "Workbook Electronic Car" consists of 18 pages each half the size of a standard sheet of A4 paper—an additional two pages for the front and back covers are not counted or discussed as they are more decorative and provide information about the non-profit but no precise information about the particular STEM project found within its pages. The workbook is divided into eight sections that are listed below in order of where they sequentially appear in the document, and how they are color-coded with either teal, orange, blue, or magenta. The sections are entitled: 1) Team, 2) The race, 3) Time to build the car, 4) The Mechanics, 5) Electronics, 6) Coding, 7) Shopping, and 8) Hints. The writing style is mostly in the form of short sentences or point form notes with occasional formatting (e.g., bold text) to highlight important information. The workbook also contains pictures, diagrams, and fill-in-the-blank exercises.

5.3.1 TEAM (teal)

The first section is one page in length and includes instructions for the participants to engage in an ice-breaker exercise followed by a written prompt to come up with a name for their team and to write it down in the workbook. The next aspect of this section is dedicated to assigning specific roles to each member of the group and outlines the main responsibilities for each role. The workbook contains color-coded sections dedicated to each of the roles. Finally, at the bottom of the page is a note to the participants about the role of the mentor as "an advisor" to help when they "get stuck" and where the mentor may provide the "right answer to get you going".

5.3.2 THE RACE (teal)

The second section is also only one page in length but the bottom half of the page is just a picture of toy cars poised to race. The written portion of this section explains that the cars built over the course of the activity will be evaluated by "a race" with "the winner" being determined based on three criteria: 1) how far the car travels "in a straight line in a specific period of time"; 2) how "much did the car cost"; and 3) how "good" does the "car look".

5.3.3 TIME TO BUILD THE CAR (teal)

This next header is only followed by the next section, which perhaps implies that much of the upcoming content or sections all fall under building the car.

Also, it is possible that having this header also implies the beginning of the hands-on portion of the activity, which encompasses all other roles and sections that follow—i.e., regardless of what role each participant has, they are all working together to “build the car”.

5.3.4 THE MECHANICS (orange)

This section is immediately under the heading of “Time to build the car” and is color-coded as orange, which means that this section is the responsibility of the group members that were selected to work on the mechanics and design of the vehicle. The mechanics section is also only one page in length and consists of three separate tasks divided into Task 1, Task 2, and Task 3.

The first task asks the mechanics to plan how the car will look with some point form questions to consider when doing so—e.g., number of wheels, balance the car so it goes straight, and how to make the car look good. The task ends with a prompt to “Sketch it out!” before warning the mechanics to be quick so that the store where they will purchase the vehicle parts does not run out of its limited stock.

The second task asks the mechanics to enter into discussions with the project leader and the other team participants about the vehicle budget and a “plan to move forward”.

The third and last task tells the mechanics to start building the vehicle and to refer to the “instructions,” “store catalogue,” and “balance sheet” that can all be found near the end of the workbook.

5.3.5 ELECTRONICS (blue)

On the fourth page of the workbook is the start of the electronics section, which continues for the next four pages. This section is color-coded in blue and is therefore the responsibility of the two group members that have taken on the roles of mechanics to work on coding and “figuring out how the electronics work”.

The first text of this section is information about what a motherboard is and how it is connected to other electronic components provided in the activity. On the bottom of this same page is Task 4, which prompts the mechanics to connect the Micro:bit and the motherboard and insert the batteries. There is a picture on the page that shows the two electronic components connected. On the following page is a relatively long section about the light sensor, which also includes a picture of what this component looks like, and includes a brief explanation about how light output can be measured as an electronic signal using the voltmeter. At the bottom half of the page, the light sensor information is followed by Task 5, which provides information and instructions about how to connect the light sensor to the motherboard. Task 6 is found on the following page and is the longest task under the electronics section. This task walks the mechanics in the group through observing, measuring, and documenting the different outputs of the light sensor under three lighting conditions: dark, ambient, and flashlight. The task concludes with an explanation about how the Micro:bit interprets ("reads") the light output and how this "controls the car".

The next section on the following page is an explanation about the motor and includes a picture of the actual component with drawn arrows pointing to "Tab 1" and "Tab 2" on the actual device. The text about the motor explains how the motor works, and at what speeds. Concepts such as "direct current", "voltage", "reduction ratio", and "torque" are all used to explain the connection between the electric current of the motor and the movement of the wheel. Task 7 is located under the explanation of the motor and explains how to connect the motor to the motherboard and asks the mechanics to provide a written answer to a question about any possible differences that can be identified if the tabs on the motor (Tab1 and Tab2) are connected in different ways.

On the next page there is information about the BBC Micro:bit with a following section that discusses this micro-computer's various pins and a link to a website that provides even more details. The last item on the page is a "Note" about not connecting 3V (three volt) pins directly to a GND (ground) pin.

5.3.6 CODING (blue)

The mechanics are not just responsible for piecing together the electronic components, but they are also tasked with writing the code to program the Micro:bit in order to control the electronics. This section of the workbook is five pages in length and includes five tasks.

The mechanics are provided with a link to a text/code editor from the BBC Micro:bit website. Task 8 asks the mechanics to test various light conditions and to program the Micro:bit to read the light output. Written in bold is a warning that the light sensor is an "analog device" and that this may have some implications for programming the Micro:bit. There is a prompt at the end of this task that points to a hint at the end of the workbook about how to consider the code. Task 8 is followed by two questions with the first asking about a "good number" to serve as a "threshold" between ambient and flashlight outputs and the second question asking why the numbers are different from those documented in Task 6.

On the following page, Task 9 has the mechanics connect the motor to the Micro:bit and to write code in order to see how the "motor goes" in response. A "flowchart" is provided on the bottom right of the same page to describe this relationship. The workbook states that if this is "hard to figure out" that another hint is provided at the end of the workbook. The last section of text at the bottom of this page is a question about why the motor is actually not working with a written answer provided immediately below, which indicates the need for an amplifier and an arrow prompt stating that more information about the amplifier can be found on the following page.

The next page has a short sentence about what an amplifier is and a picture of the component beside the explanation. The last section of text on the page is Task 10, which asks the mechanics to add the amplifier to their build and to test the motor again with a flashlight.

The workbook moves on to the next page and Task 11, which asks the mechanics about how they would connect a second wheel to the amplifier and to actually “Sketch it out” in a square space provided on the same page. The last text on the page prompts the mechanics to “Now connect them!” before moving on to Task 12 and Task 13 on the next page.

Task 12 instructs the mechanics to “Change the code from Task 9” to allow for “delay” so that the motor does not stop moving once the light source is removed. There is another “flowchart” provided on the inner side of the page that is meant to guide the mechanics in changing their existing code. Finally, Task 13 tells the mechanics to actually put the car together and to “test it” in order to make any adjustments that may be needed. This section concludes with a bold “Congratulations!” and states that the car is now ready to race.

5.3.7 SHOPPING (magenta)

The fourteenth page of the workbook has the section that explains the dynamics of shopping for parts for the vehicle and what the budget is. This section only takes up the upper half of the page and includes information about “returning parts you don’t need later” and states that participants of the workshop are not allowed to use “any other material apart from what is sold at the shop”. The participants are also reminded not to destroy the electronics, which include putting hot glue on them. The last sentence on this page suggest to keep track of purchased items on the following two pages referred to as the “balance sheet”.

5.3.8 BALANCE SHEET (magenta)

The balance sheet provided on pages 15 and 16 of the workbook is a simple table with 24 rows alternating between white and a colored row and four column headings called (from left to right): “Item,” “Money Spent,” “Money Returned,” and “Money Left”.

Accompanying the balance sheet on page 17 is the catalogue of shop items, which is a picture the size of the page that shows an overhead view of the shop items and their respective prices. The items include both electronic components and building materials for the structure of the vehicle itself (e.g., wooden stick, popsicle stick, plastic box) and additional items such as wire, glue, tape, battery, bottle cap (with a hole in the middle), and rubber band. Prices for the items are listed as 1sek, 2sek, 5sek, and 20sek. All of the electronic components were priced at 20sek.

5.3.9 HINTS (teal)

The last page of the workbook shows pictorial hints to Task 9 and Task 10, which are both part of the coding aspect of the workshop. The images show small sections of the Micro:bit code formatted in a block coding style with some words mostly redacted in white but potentially still discernable within the context of the tasks they are associated with.

5.3.10 WORKBOOK WORDS

It is possible to examine the workbook according to some keywords that can be related to epistemics for either STEM knowledge and more abstract 21st century skills grouped according to the 4C's of creativity, critical thinking, communication, and collaboration. This list of words is provided in Table 6.

Table 6: List of Keywords from SDP Case Workbook

STEM Keywords	21st Century Skills Keywords
friction, mechanics, gravity, designers, coding, balance, motor, build, look/design, motherboard, create, Mico:bit, edge connector, input, output, pins, volts, 3V, GND, P0-P20, photons, sensor, power, measuring, signal, visible light, ultraviolet, infrared, voltmeter, ground, direct current, DC, ratio, drag, microcomputer, program, read out, torque, GPIO, 'website links', brain, text editor (Make Code), test, analog, threshold, amplifier, amp, IN1, IN2, UT1, UT2, series, parallel, 'block code examples', sketch, flowchart, adjustments	team, introductions, roles, communicate, budget, design, test, "understand all parts", plan, discuss, agree, 'questions to prompt critical thought', create, 'website links', 'brain analogy', coordinate, decide, sketch, 'theoretical question', change, participate, adjustments, "not allowed"

5.3.11 The SDP Workbook as an Epistemic Frame

Looking at the workbook and determining how the words used in the document reflect constructs of STEM and 21st century skills reveals only one facet to the value of this document in evaluating the SDP activity. The workbook itself represents an idealized conception of how the activity may unfold. The workbook directs the participants to perform particular tasks related to building the electronic vehicle, but the workbook also prompts moments that can be interpreted as encouraging the use of 21st century skills including the coded epistemics that are explored in this study.

The workbook that was included in the SDP workshop was originally not expected to be an important factor or component of the STEM cases. In fact, it was not until the delivery of the mentor training case and the SDP workshop case that the existence of a workbook was introduced to the study. For this reason, the analysis of the workbook is conducted slightly differently with respect to the data segmentation and the selection of the activity and units of analysis.

From an analytical perspective, the workbook is considered as a manifestation of the idealized version of the SDP workshop. The workbook outlines not only what is to be accomplished and in what stages, but also provides prompts that can guide the practice of 21st century skills at specific segments of the activity. It becomes an interesting facet to this study to determine not only how the segmentation of the workbook compares to the division of labor in the activity between the participants, but also if the connections made between STEM knowledge and 21st century skills are similar between the workbook directions and the actions and conversations of the participants.

The networks for the workbook are segmented based on how the workbook divided the activities and responsibilities among the participants. The codes are the same as present in other network plots and represent the epistemics for STEM subject knowledge and 21st century skills. The epistemic frame and the network model for the workbook are provided in Figures 29 and 30, respectively.

When looking at the epistemic plots for the workbook, it is important to note that the entire STEM activity can be described by the key locations for each of the four color-coded sections of the workbook and the related activities assigned to the participants selected to take part in each section. The sections are identified as: Blue for Electronics and Coding; Magenta for Budget and Project Management; Teal for Planning; and Orange for Design and Testing. The epistemic frame is generated based on all of the coded epistemics and the overall workbook plot presents where each section is situated within the frame. The network models are provided for each of the colored sections and presented in Figures 31 to 36.

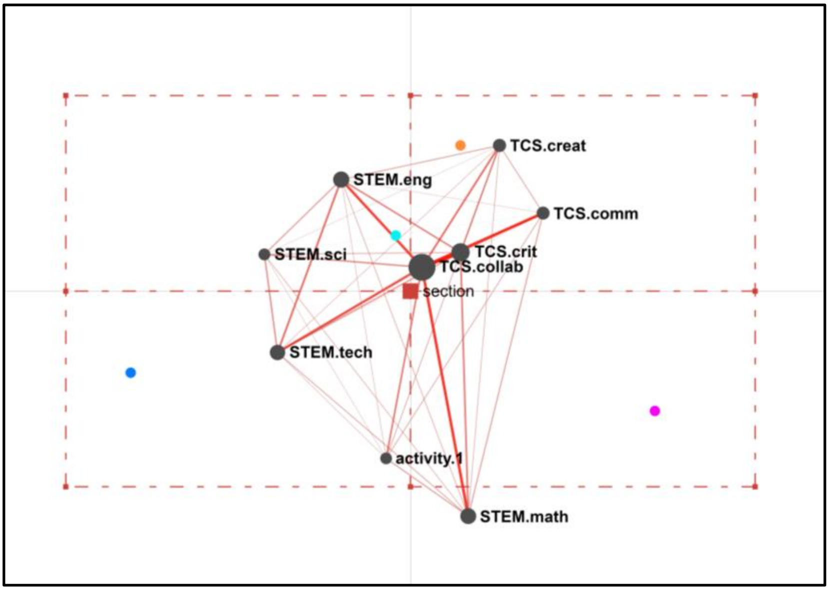

Figure 29: Epistemic Frame for SDP Workbook

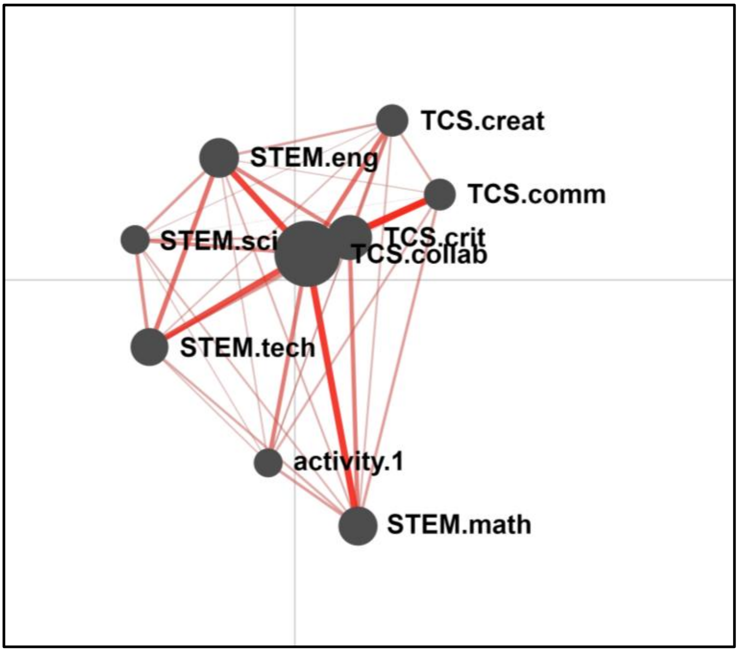

Figure 30: Network Plot for SDP Workbook

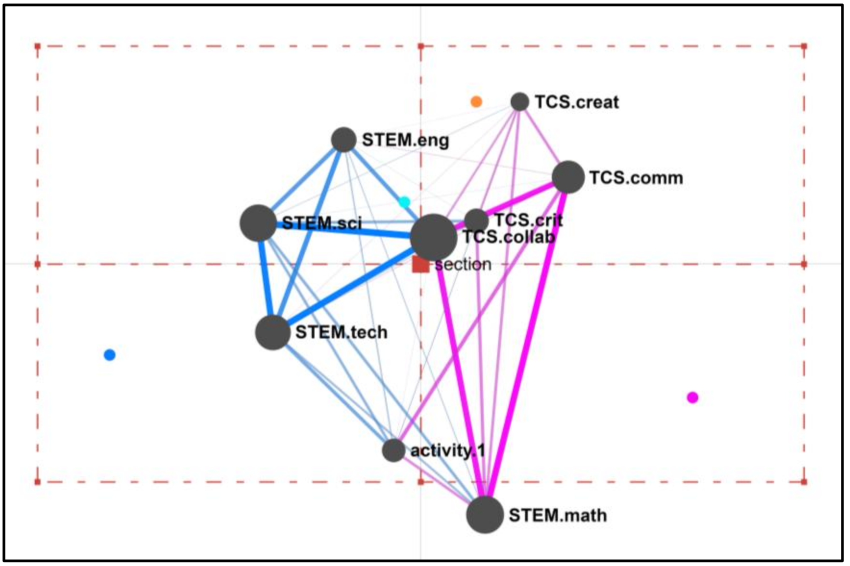

Figure 31: SDP Workbook Networks for Electronics and Project Leader Sections of the workbook are Electronics (blue) and Project Leader (purple).

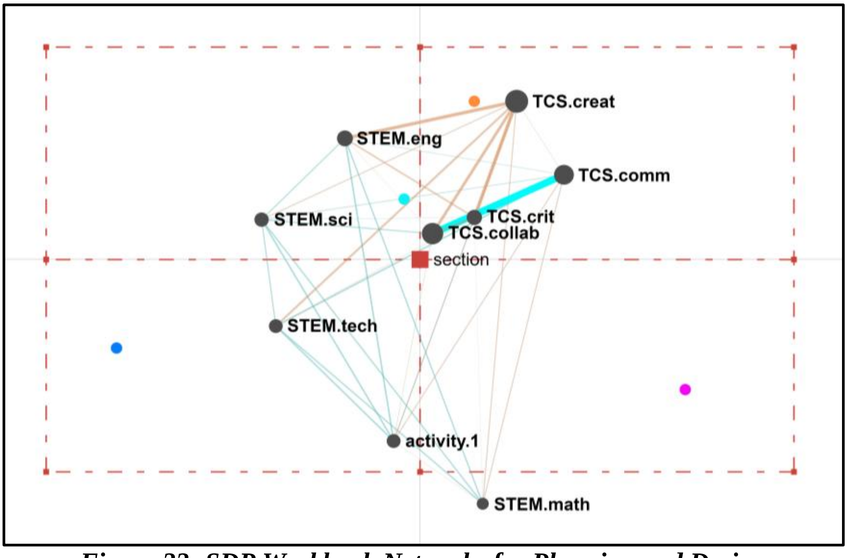

Figure 32: SDP Workbook Networks for Planning and Design Sections of the workbook are Planning (teal) and Design (orange).

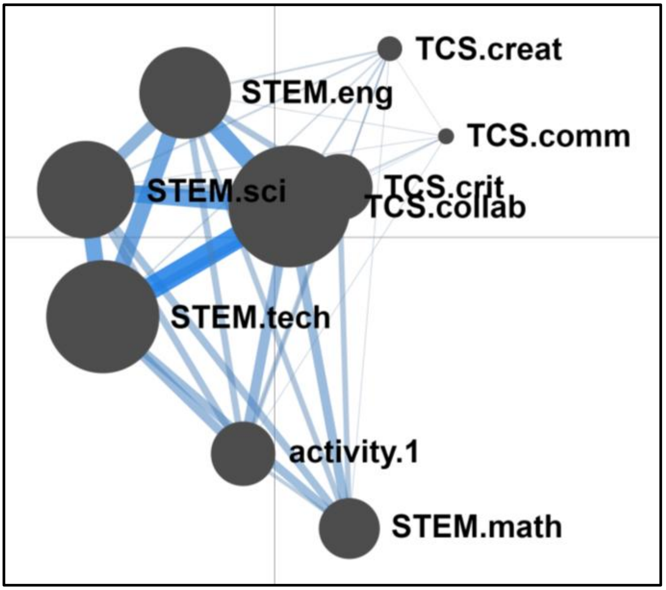

Figure 33: Network for Electronics and Coding Sections of SDP Case

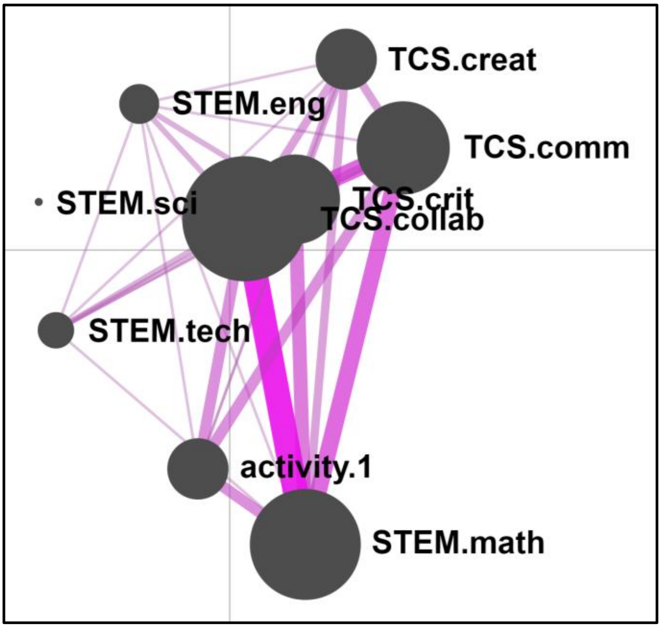

Figure 34: Network for Budget and Project Management Sections of SDP Case

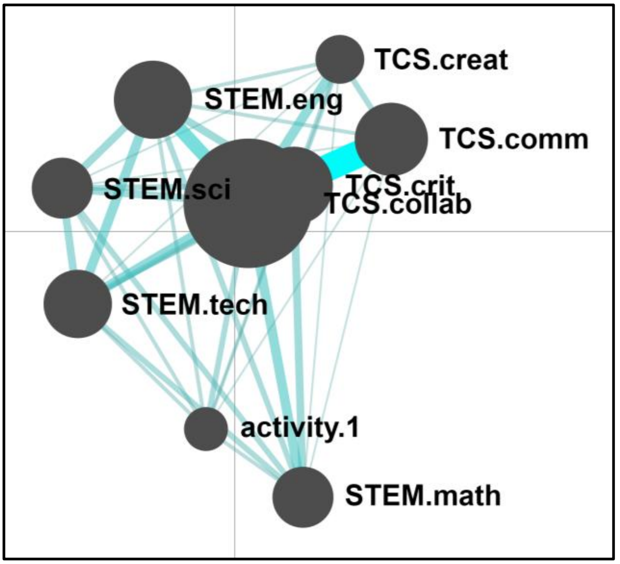

Figure 35: Network for the Planning Section of SDP Case

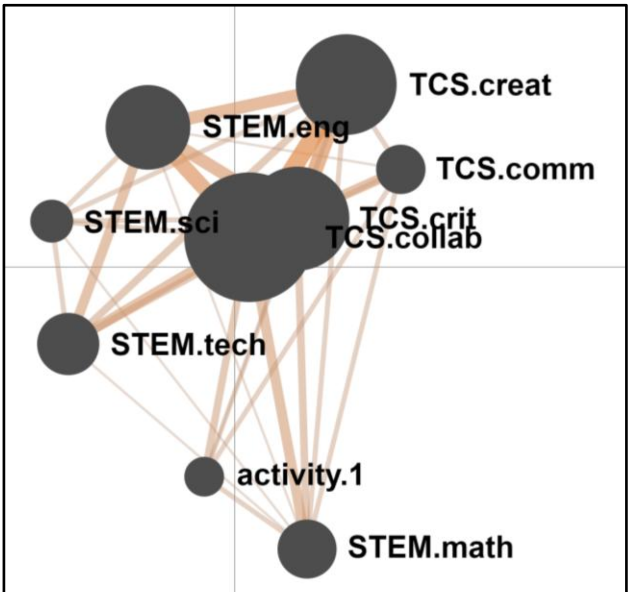

Figure 36: Network for Design and Testing Section of SDP Case

The epistemic frame that is generated for the workbook, has a notable pattern with respect to where the sections of the activity are placed in relation to how the coded epistemics are dispersed along the multidimensional space. In general, the STEM subject epistemics are located on the left side of the frame, with the exception of mathematics, which is located on the bottom right of the frame. The 21st century skills epistemics are located within the upper right of the space. In general, this allows for interpretations about how the nodes for these sections are related to the weighted connections made in its corresponding network.

The general pattern in interpreting the workbook epistemic plot is to understand that any node located more to the left of the space is going to showcase greater cooccurrence with STEM epistemics, and nodes situated closer to the center of the space or situated in the upper right are going to display more connections among the 21st century skills epistemics. Based on the plot for the activity workbook, the feature of collaboration is the most prevalent of the skills that cooccurs with the STEM epistemics, but that the other skills do not have many connections when compared to the other sections of the activity. Not surprisingly, the magenta node for the Budget and Project Management of the activity was the strongest manifestation of Mathematics in the activity.

The blue section on electronics and coding is represented by one blue node and is located on the lower left side of the epistemic frame. The teal node for Planning is located slightly left of the Y-axis and slightly higher than the X-axis. The orange node for Design and Testing is located at the higher end of the space and slightly to the right of the Y-axis. The magenta node for Budget and Project Management is located at the further right of the space and also further down from the X-axis.

Despite the varied locations for each of the nodes for the workbook sections, the webENA tool calculated a goodness of fit of 1.00 (Pearson) and 1.00 (Spearman) to determine that all of the network representations of the sections fit the model of the overall STEM activity. The original model places the STEM epistemics for Science, Engineering, and Technology on the left of the Y-axis, which corresponds to the location of the blue node and indicates that the network related to the blue node will be more weighted among these epistemics. When compared to the sections for Planning and Design and Testing, it is clear to see that these sections are located more to the center and upper section of the space, which indicates that more connections will take place with and among the 21st century skills.

When comparing the network of the workbook to the network of the SDP Teacher Workshop case (see Figures 37 to 39), it is possible to visualize the difference between how the activity is described and organized within instructional material and how the activity is enacted by the participants. One of the most striking distinctions is that the workbook signifies more connections between the STEM epistemics while the enactment of the activity by the SDP teacher participants (and mentor) signified stronger connections between the 21st century skills epistemics.

Although this may seem uninteresting in light of the fact that the comparison is between a fixed object with static and rigid instructions and information, and with the dynamic processes and utterances displayed by human participants engaged with the activity, there are still some possible implications to this comparison. First, it is possible to identify within the Data View that the sorts of scientific concepts and themes shared within the workbook are not manifested in the conversations taking place between the participants. This implies a disconnection between the sorts of knowledge this activity is meant to build upon and what sorts of knowledge are being physically recalled or applied by the participants.

Also, there are possible implication for how instructional resources can or cannot be used to encourage the enactment or practice of 21st century skills, especially those like creativity. That is, with clear directions and stages outlined in helpful detail, the activity becomes more structured and opportunities for novel interpretations or actions that deviate from the workbook may be unintentionally discouraged.

Another important facet to the conceptualization of the workbook as an artefact/actor within the activity, is how the workbook is included in the networks of the participants based on its use as a communicative tool to improve on efficiency of sharing or clarifying ideas, and to help identify items within the activity that are not familiar to all of the participants. Overall, the role of the workbook adds an interesting point of analysis for understanding these particular STEM activity cases.

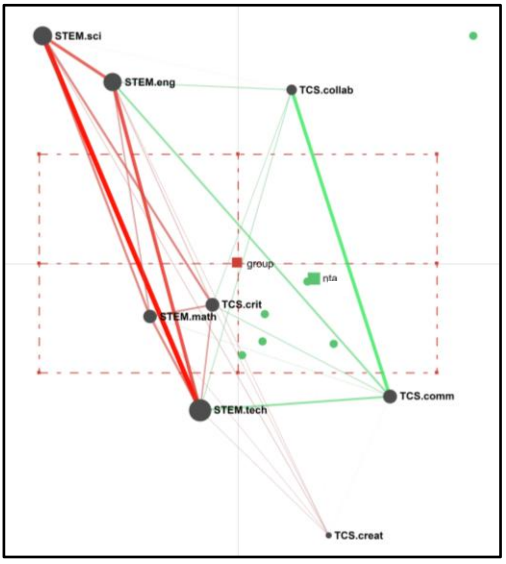

Figure 37: Network Comparison Plot for SDP Participants and Workbook
The SDP participants (green) and the workbook (red) compared.

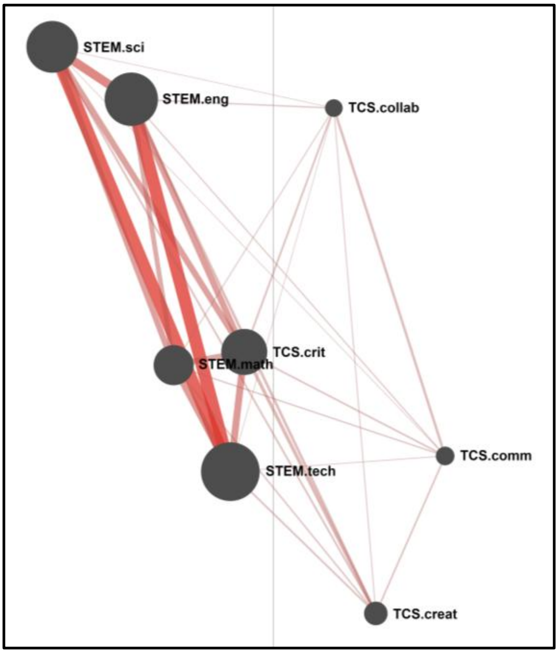

Figure 38: Network Plot for SDP Workbook

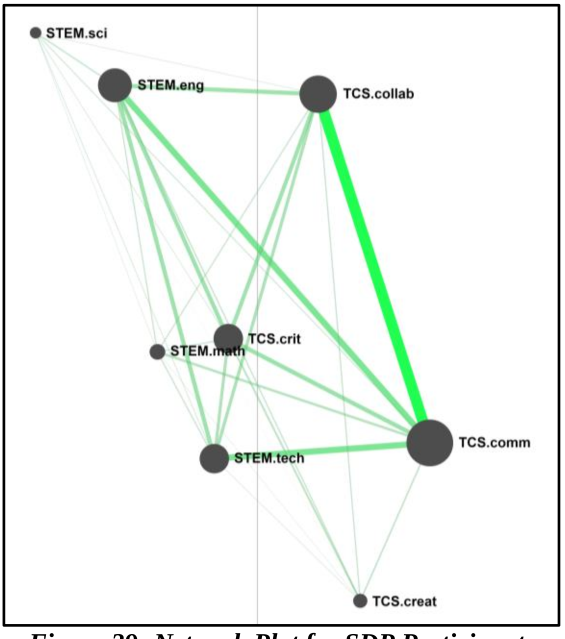

Figure 39: Network Plot for SDP Participants

5.4 Qualitative Document Analysis and Emerging Themes

When undergoing the epistemic network analysis (ENA) several points of interest were brought to light that inspired a deeper investigation of the audio-visual data and transcriptions. This deeper investigation brought about a better understanding of the contexts of the STEM activity cases, in addition to setting the groundwork for attempting to close the analytical loop between the ENA findings and the ethnographic foundations of the data as generated by the participants of the activities. This deeper investigation into the information revealed by the ENA was conducted using a Qualitative Document Analysis (QDA).

The use of QDA is generally quite flexible and allows for investigating both *documents* in either visual or textual formats, and tangible, three-dimensional, *artifacts* that the participants interact with in an environment (Merriam & Tisdell, 2015). Within this research project, the documents are identified as the source video data and the transcriptions of the verbal and nonverbal communications. The video data was revisited within the Transana software, while the transcripts were accessed from the Data View of the ENA Webtool. By returning to these documents, it was possible to explore the verbal and nonverbal interactions taking place in accordance with points of interest highlighted within the ENA network plots. This allowed for the ability to assign thematic concepts to explain and categorize the findings of the epistemic analysis, which are outlined and explained within the upcoming discussion of the results (see 6. Learning from the STEM Activity Cases: Discussion of the Results).

Furthermore, conducting a QDA, is a way to apply a qualitative triangulation of the ENA findings, which is often an application of QDA within mixed-methods research (Morgan, 2022). The use of QDA in this manner is used to uphold the findings of the analysis by determining what, if any, interesting points of discussion can be attributed to the findings that go beyond the simple recognition of interesting patterns of cooccurrences within the ENA plots.

The following chapter outlines the ostensible thematic concepts that emerged from the combined investigation of the ENA models and the source data underpinning the key trends within them.

6. Learning from the STEM Activity Cases: Discussion of the Results

The results of the ENA network investigation, together with looking into the conversational and interactional data associated with segments of the networks, reveal patterns within the cases that help to structure a discussion about how STEM learning is encouraged or hindered within the cases examined here. The findings from this research project are presented according to how the results of the analysis directly address the key research questions, while also stimulating insights into factors of STEM learning that were not originally considered.

Findings that came out of the use of ENA allowed for the visual interpretation of knowledge and skills relational cooccurrences within each case. These network visualizations were unique to the groups and individuals within each case and allowed for comparisons based on two key units of analysis: the STEM activity itself; and the individual participants within each group. One general outcome that was detected in each of the three STEM activity cases, was a statistically significant difference between the STEM activity participants and the instructional actor within the context (i.e., non-profit staff or mentors). There were also marked differences between participants taking part in the same segment of an activity. This points to a possible implication for the learning context of these STEM cases with respect to how groupwork dynamics can be applied to better align with the need for all learners to gain access to all of the various aspects of a complex problem-based learning activity that attempts to integrate all four STEM subjects.

Continuing from the groupwork dynamic, there is also a need to consider the communicative factors that are reflected in the context of these cases, and how they can be understood with respect to the use of ENA, which has been predominantly used on conversational data within an online environment. The manners of communication applied within the cases examined in this study, point to the unique characteristics of in-person communicative tactics that can play an important role in how to design collaborative STEM activities and environments for both digital and in-person deliveries, especially if both modes of delivery are intended to apply active learning principles.

The network plots also served to provide a general understanding of how to conceive of the STEM activities in terms of the relationships between the coded epistemics (i.e., STEM knowledge and 21st century skills). All of the networks showed complex interactions between the two categories of epistemics for STEM knowledge and 21^{st} century skills. Some of these cooccurrences were stronger than others and showed what segments of the activities were suited to presenting stronger connections between the various skills and knowledge constructs targeted by the STEM activity. One key result was that the STEM epistemic for Mathematics was generally seen to have weaker connections when compared to the other STEM constructs.

Another theme to explore, based on the findings of this study, is the role of the teaching materials provided within a STEM activity context. Furthermore, it becomes important to understand how this artefact is conceived of in terms of the contributions it can or cannot make to the pedagogical framework underpinning the design of a STEM activity. Because the STEM activities examined here were not organized or designed as part of this research project's methodology, it was not possible to make theoretical predictions about specific participant-artefact interactions despite the analytical decision to partially interpret the STEM cases based on various facets of interactional data. This is made clear with the introduction of the workbook included in the mentor training case (case two) and the teacher workshop case (case three).

The data analysis highlighted the unique importance of the instruction booklet (i.e., workbook) that was included in the latter two STEM cases but which was deliberately not present in the hackathon case. The sheer volume of interaction that took place between the participants and the workbook suggests the need for an in-depth discussion about the possible contributions teaching materials made within these STEM learning activities, and how this can contribute to the body of academic literature on STEM education. Although not originally considered, an ENA analysis was also conducted that compared the epistemic network generated by the workbook and the epistemic networks generated by each STEM activity case to detect similarities or differences between them.

When considering the findings that were not originally considered when examining the STEM activity cases, the concept of cheating is an interesting outcome that requires greater investigation within the context of problem-based activities that do not adhere to the rigid assessment practice of traditional education. Unlike traditional educational activities with clearly defined objectives, usually only one designated correct answer, and which often require proofs to how solutions are derived, these STEM activities remained relatively open-ended and agreeable to multiple directions to pursue solutions. Cheating, within the STEM activities examined over the course of this research project, is examined from a perspective that dismantles this rigid duality of right and wrong solutions and practice in light of the connections cheating displayed between 21^{st} century skills such a creativity and critical thinking.

Finally, the formulation of an anatomical structure of the STEM activity cases examined here helps to indicate a pathway to closing the analytical loop when attempting to understand the learning outcomes of STEM activity participation. The idea that a STEM activity has a predetermined framework that can guide the interpretation of learning outcomes can limit understanding of the more complex nuance of how a STEM activity is enacted and shaped by the participants who undertake it. Again, this may seem to imply a constructivist approach to understanding STEM activity learning, however, this is not strictly the case when considering the relationship between data-driven approaches to understanding learning data and its relationship to learning theory as underpinning STEM contexts. Simply put, the specific unit of analysis and the scope of this mixed-methods study are not best-served when confined to rigid methodological constraints during analysis.

The notion of how enactment by STEM activity participants shapes their epistemic frame can be empirically applied to a predefined anatomical structure that is skeletal when theoretically proposed, but lacking in the muscular refinement that can be developed by real-time and dynamic learning data. This more positivist perspective acknowledges a constructivist pathway to future and further investigation into the details of the thicker and deeper soft tissues that now rest on the surface of the underlying STEM framework. However, in order to provide an explanation behind how learning can be meaningfully understood within the contextual background of a STEM activity, an approach that limits the agential factors to those outlined within the STEM activity context helps to provide more meaningful information about how this case study can contribute to research into STEM within unrelated contexts.

Most importantly, this section discusses the findings from the ENA investigation in a manner that serves to answer the research questions about the structures of the STEM activity cases and how they align with other STEM learning frameworks while also looking to see how the participants make connections between STEM knowledge and 21st century skills when engaging in the activities. The discussion about the research questions is framed within the analogy of looking into the black box of the process of the STEM activities.

Finally, the roles of the mentors and the hands-on activity of “making” is reconsidered in light of the findings. All of these aspects are considered within the scope of identifying opportunities for learning that manifest based on the structures and interactions taking place within the STEM activities and the various human and non-human actors that comprise them.

6.1 Science, Technology, Engineering, and (Maybe) Mathematics

One of the claims regarding the laudable quality of STEM education and STEM activities is that the four subjects of Science, Technology, Engineering, and Mathematics are integrated into one interconnected and overlapping subject that allows for a more comprehensive and realistic use of the subject matter when solving real-world problems outside of a purely educational arena. However, it is often the case that unequal attention is given to all four of the subjects within the same teaching activity, and it is often mathematics that is not addressed to the same extent. One of the main reasons for this can be related to the level of comfort a teacher has with mathematical concepts and how to apply these concepts in creative and flexible ways that allow for integration with other STEM fields (Hasek, 2024). The trend for the underrepresentation of Mathematics within STEM activities, and STEM education in general, is reflected and supported by the findings of this study.

Within the STEM activity cases examined here, the weaker connections made between mathematics and the other STEM concepts are attributed to the conversations and actions of the participants. This makes it difficult to consider the variables of how the activity was designed as regards the integration of mathematics to a similar degree as the other three STEM subjects. What is clear from the data is that mathematics is discussed less and applied less frequently within the course of the STEM activities examined here. This is most obvious when looking at the network models that tend to position the mathematics node further away from the other STEM epistemics and often closer to the 21st century skills. This implies that the cooccurrence patterns among the epistemics are different for mathematics than for the other STEM epistemics, but that mathematics can be a valuable contribution to encouraging the use of 21st century skills during STEM activities.

These weaker connections between mathematics and the other coded epistemics can indicate a possible point of intervention for considering how to improve the integration of mathematics for other STEM activities. For example, when reviewing the utterances and interactions that take place when mathematics is mentioned within the first two cases and the last case, there is a difference with how engineering students and the teachers apply mathematics. With the engineering students, the connections with mathematics were made more with engineering and technology and were focused on understanding the functions of the amplifier for voltage conversations and the ratios of how power is increased as a result. For the teachers, the cooccurrences with mathematics were with the design, critical thinking, and creativity epistemics and focused on discussions about how to budget the building of the vehicle.

Another discussion that requires attention is the comparison of the three cases in terms of their respective epistemic frames and how the network models are positioned within them. All three of the cases involved the same general concepts and technical requirements, and so it is reasonable to suggest that the participants were the deciding variables in how knowledge and skills in the STEM activity networks were connected. When it comes to improving the integration of mathematics, there is a possibility to have mentors or instructors scaffold learners by bringing attention to how mathematics is situated within the activity and help to make this feature more overt when mathematical aspects are being undertaken or investigated by the participants.

The application of ENA methods allows for identifying what conversations and/or interactions are associated with any possible occurrences of mathematics in combination with the other epistemics. The use of ENA can therefore be applied to improving situational aspects of a STEM activity by identifying gaps in reasoning or explanation that can showcase a deeper integration of mathematics in instances where the activity draws direct attention to mathematical applications or reasoning.

6.2 Teaching and Learning Materials and the SDP Box

The STEM cases examined in this study were part of a partnership between a non-profit and a Swedish organization that was running a school development program (SDP) for compulsory school teachers. This partnership tasked the non-profit to develop a workshop for Swedish school teachers to familiarize them with an activity for teaching the programming functions of the BBC Micro:bit to their respective students alongside the hands-on introduction to technology via the building and functioning of the electronic components.

As stated earlier, this research project collected data from these existing cases of non-formal STEM activities. As a result, the design of the activities around a thematic "kit" with the necessary learning materials and information already provided was not known prior to data collection. The application of the SDP "kits" (i.e., thematic boxes) provided an interesting variable to consider within these cases, and requires some understanding of this variable in relation to its role as a learning material input included in the STEM activity context.

The aim of the SDP Teacher Workshop STEM activity was to provide the Swedish teachers with instruction and practical hands-on experience with the activity contained within the SDP box. The activity served to help the teachers understand the technological details and tasks within the activity that combined the use of electronic components and the BBC Micro:bit's block-based coding application, otherwise known as a Visual Programming Language (VPL). Unlike the engineering students within the previous two cases, the teachers did not move beyond the scope of the VPL, nor did they consider hacking the microprocessor based on the sorts of sensing components the SDP box included. The teachers worked well within the bounds of what the SDP box provided and the intended uses of the materials. The mentor did not introduce the more complex affordances of the activity either, such as hacking the Micro:bit using more technical coding languages or platforms.

However, despite the focus of the SDP thematic unit box as a convenient learning material that highlighted the coding functionality of the BBC microprocessor via its simple Programming Language Environment (PLE), the convenience of an outlined activity with all of the necessary components included, resulted in a more structured activity for the teachers that did not showcase as much deviation from how the task was designed by the non-profit. The teacher workshop case was less open-ended than the previous two cases. In addition to the materials framing the scope of the activity, and the possible pathway to addressing the task of the SDP box, the inclusion of a workbook provided further direction and scaffolding to the teachers during the activity. This is not unlike how a study on the use of STEM kits in the home found that the inclusion of materials and guided activity workbooks resulted in reports of improved STEM-skills learning for the children, and greater self-efficacy on the part of the parent to foster the STEM learning of their child (Carroll & Scott, 2017). It is possible to consider the use of a STEM kit within this third STEM activity case as serving to improve STEM learning, but that this may come at the risk of restricting some 21st century skills that are needed when tackling a more open-ended problem with less directed pathways to creating solutions.

Although a direct comparison with the epistemic frames and the corresponding networks for each of the cases cannot reliably address this query, it is interesting to note that the two STEM activity cases that were not formally guided by a refined SDP box had more connections with 21st century skills epistemics such as critical thinking and creativity. These connections were associated with conversations about various directions and solutions that could be undertaken within the activity. The teacher workshop STEM activity showcased conversations about creativity and critical thinking with respect to executing the activity within the establish rules and confines of what was provided by the kit and outlined in the workbook. However, this may simply point to a connection with increased application of creativity and critical thinking once a proficiency with subject knowledge (in this case STEM subjects) has been achieved (Kenett, 2025), and not related to the use of the SDP box.

In order for the SDP thematic box on technology and programming to be adopted by the Swedish teachers, there needed to be a level of comfort with the required knowledge and skillsets to use the kit and complete its associated activity. The use of a STEM kit as a Teaching and Learning Material (TLM) allows for teachers to focus on what is needed for the specific activity of the kit rather than attempting to understand broader and more complex topics within the field of general STEM education. However, there is research that suggest including teachers in building the kits as a form of pre-service teacher training could be more valuable to improve STEM pedagogical teaching skills and for the improved interdisciplinary understanding of the connections between the four STEM subjects (Carroll & Scott, 2017). For this reason, it is important to consider the SDP unit boxes as valuable for developing specified knowledge and skills, but perhaps limiting in translating these skills and knowledge beyond the scope of the SDP box project or theme.

When considering the value of STEM kits for STEM learning, it is important to ensure alignment with what learning outcomes are sought. For example, the programming of the Micro:bit was discussed only in terms of its VPL and how to accomplish a specific task, instead of its applicability for other scenarios. The Micro:bit could be used with other programming languages such a JavaScript, as seen with the engineering students and mentor cases, but in order to implement the SDP box in the classroom, a VPL that the teachers were familiar with, and could confidently use, was of primary focus. This may account for the limited coding functionality applied to the Micro:bit in the case of the SDP STEM activity, but which could have perhaps improved the likelihood of application of the SDP thematic unit in the classrooms of the participating teachers. This may be especially true when considering the common practice of using VPLs such as Scratch and other block-based text environments in compulsory school. The network for the teachers showcased weaker overall connections with the STEM epistemics when compared to their mentor and when compared to the other cases, which could indicate more limited comfort with more technical aspects of the SDP thematic unit—including the coding of the BBC Micro:bit.

With respect to how pedagogical materials that are focused on STEM subjects, and themes related to teaching computer programming, it was found that Swedish teachers selected materials based on "the characteristics of the PLE, the teacher's own education and the curriculum" (Hasek, 2024). The decision to use the BBC Micro:bit as a TLM in service of the programming curriculum has already been supported by *Skolverket*, and with the targeted VPL skills taught with the SDP thematic box there is more likelihood of successful implementation of this STEM activity in a Swedish classroom that is in service of this Swedish programming curriculum (Kvaššayová et al., 2022).

The findings of this study did not originally consider the role of the SDP thematic unit, nor its intended use as a TLM within the examined non-formal STEM activities of this research project or in subsequent formal STEM classrooms. However, this research project can make a subtle claim about the role of the SDP thematic unit as a TLM that has implications for how connections are made between STEM subject knowledge and 21st century skills within the teacher workshop case. It is clear from the ENA of the three cases that the teacher case showcased less connections with science and engineering epistemics despite having more resources to access and adopt these concepts (e.g., the workbook and an experienced mentor). The SDP thematic unit, if not thoughtfully applied within a STEM activity, may run the risk of wrongly assuming what subject knowledge and skills will manifest by the learners.

Although the main aim of the SDP hackathon was to help teachers to accomplish the goal of utilizing the educational supplies within the box to aid in teaching technology and programming, it is hard to indicate from the video data itself if this consideration was addressed by the teachers during or after the activity. What would be fruitful to consider for future research is how taking part in this SDP workshop might have impacted upon their integration of the materials into their classrooms and what subject matter (electronics, mathematics, science, etc.) they were able to link to the use of the box. Furthermore, it would be interesting to investigate if the teachers experienced insights into integrating the SDP box into their classrooms, and if this came about as an act of reflection or as an active thought during the STEM activity.

6.3 Divide and Conquer: Thesis and Antithesis to STEM Success

Across all three of the STEM activities the participants were organized into groups at various levels. All of the participants were first divided into groups of between two and five individuals and were situated at sperate tables. At each of the tables, the groups were then further subdivided into pairs or individuals and assigned to specific tasks within the scope of the whole activity.

This division of labor was determined by the organizers of the STEM activities and not by the participants themselves. Despite the exact reasoning behind this decision not made clear, the implications of this divided groupwork design were apparent within the analysis. This division of labor can be discussed in two ways in terms of the 1) groupwork division, with how each group was placed at separate tables, and as 2) role-assignment, with how each individual at each table was given a specified section of the activity to undertake. More attention will be placed on role-assignment, however, based on the data collection strategy targeting one group within each STEM activity case.

With respect to the partition of the overall activity into distinct role assignments, the ENA showed that most sets of roles and responsibilities fostered significantly different epistemic networks. The networks for each role assignment often reflected subject knowledge and skills that were most obviously relevant within the domain of the specific task. The network that resulted from the specific segmentations of the overall STEM activity showcased how these role assignments situated participants within the overall STEM activity epistemic frame, which was generated from all of these segments combined.

For example, in the third case involving the teachers, the participant responsible for project management and budget showed increased connections made between the various epistemics and the node for mathematics. This connection to mathematics was often present with discussions of budget and designing the vehicle in a budget-friendly manner and so limited the influence of the mathematics epistemic to only one or two participants. This is supported by looking at the networks for the participants working on coding or the electronics and how weak the connections to mathematics were.

When looking at the participants responsible for the coding and electronics segments, it is possible to also see weaker connection strengths with 21st century skills. This is most obvious with the example of the creativity epistemic, which was shown to have the weakest connections for the networks of the electronics and coding participants, especially in cases two and three. This may be due to the rigid outline for how to accomplish the coding and electronics segments of the activity, which in the case of the SDP teachers limited the opportunity of these participants to practice creativity in combination with the technical and hands-on activities associated with coding and building the electronics.

On the other hand, the designing of the vehicle within all of the cases showed relatively stronger connections between STEM-based ways of thinking and the practice of 21st century skills. When looking at the ENA models for the first hackathon case, the students involved in the design and constructions of the vehicle showed stronger connections with 21st century skills epistemics such as creativity and critical thinking than the epistemics for STEM subject knowledge such as technology. If a STEM activity is segmented according to very distinct units, it is very possible that not all of the participants will have the same opportunities for learning STEM subject knowledge or to practice 21st-century skills. This implies a limitation on how integrated a STEM activity can be when designed with regimented groupwork dynamics and divisions of labor.

This furthermore creates limitations on the cooccurrences of STEM and 21st-century skills epistemics, which calls into question the claims that STEM activities inherently promote soft skills development. Although the overall epistemic frame for the STEM activities investigated here showed promising patterns of cooccurrences between STEM and 21st-century skills constructs, the network models for the individual units of analysis revealed an unequal distribution to these cooccurrences. The issues with balancing the cooccurrences of knowledge and skills epistemics is also witnessed with an imbalance between the integration of each of the STEM subject into the overall activity.

The hallmark of STEM education and STEM learning is to showcase learning opportunities that blend aspects of each subject into the problem and solution of the activity. The cases in this example, most noticeably among the case with less knowledgeable participants in the niche of engineering and technology, reveal that not all of the four subjects are represented equally. This imbalance in the integration of the STEM subjects is present not just based on the segmentation of the activity into separate domains, but also with a general trend in some STEM subjects being more overtly expressed within the activity while others were less obviously expressed. This is most prominent with the underrepresentation of mathematics, which is shown to be a common critique of the truly integrated nature of STEM education and learning.

When considering how to encourage the integration of knowledge and skills within a STEM activity, it is possible to suggest that a division of labor is best avoided. The cases in this study had the participants select only some portions of the overall project to focus on, and this created different networks of epistemics being manifested. For the STEM case of the teachers and the engineering student hackathon participants it was apparent that some individuals reflected networks of subject knowledge and 21st century skills that deviate to a significant degree from the overall aggregate activity network. This suggests that in order for all participants to engage with the CoP represented by the group epistemic network more equally, all individuals should take part in all aspects of the STEM activity.

Moving forward from the ENA of each case, a review of the data from a qualitative document analysis of this division of labor showed that participants, especially in the case of the SDP teacher workshop, would prefer to take part in all aspects of the activity by verbalizing objections to being relegated to only one thematic task. Furthermore, when examining the data from all three of the cases from a qualitative perspective, it was apparent that having groupwork, which is beneficial in some contexts and serves particular pedagogical roles in the classroom, resulted in curiosity about the goings-on within other groups.

Furthermore, it is possible to extrapolate the group findings to the collection of groups for each activity. Despite the limitation of this study not being able to capture more than one case/group of participants within each ENA exploration of the data, a qualitative investigation of the videos based on background elements showed that each group worked differently with different results—e.g., all the groups produced different types of vehicles that performed differently. It is possible to conclude that different groups would have had unique epistemic frames and networks when compared to the groups that were subjected to data collection. An integrated CoP within the context of the entire activity across each participating group could help to share knowledge and introduce new opportunities to practice 21st century skills that would not be available to a partitioned STEM activity context.

As a final note, it is important to address the finding that participants working together on the same aspect of the activity produced network models with centroids sometimes located further apart than even participants from other tasks. No clear explanatory factors from the Data View could account for this trend, however, there did seem to be a dynamic within the conversations of these participants that placed one participant in a more dominant role than the other, which may have some implications for this finding but would require more analysis to fully understand.

6.4 Methods of Communication: Identifying Epistemics from In-Person Talking Instead of Online Typing

Although not all of the ENA literature is based on the use of data generated from online or other digital media, much of the methodological guidance from studies related to this research project heavily rely on the use of conversational and interactional data generated from sources such as chat logs, MOOCs, or online learning simulation games. This project took a different approach to the source data in light of the in-person and hands-on nature of the STEM activity cases explored. The implications of this were originally thought to be methodological with respect to the application of ENA and the coding of epistemics. However, upon transcription of the data one obvious and yet interesting result of this difference meant that communications based on talk reflected the nature of how individuals speak (i.e., in-person talk) and not on how individuals write (i.e., online chat).

This created a unique opportunity to address the use of ENA with talk data generated in real-world, dynamic, and collaborative activities rather than with computer mediated communication (CMC) and chats via online collaborative communication. To avoid begging the question, it is important to establish that there is indeed research to support that these two avenues for communication are different. For example, (El Khashab, 2023) found that face-to-face (F2F) communication is more effective and productive while online CMC is easier and faster when investigating academic collaboration in research projects and academic supervision. There is general agreement about the tradeoffs between using F2F or CMC within a learning context, and that the former tends to create more shared norms and improved understanding but can be more time-consuming in collaborative settings, while the latter can be efficient but generate more conflicts and uneven participation in collaborative settings (Ishtiaq et al., 2024). What is most distinct about these two modes of communication, especially in collaborative tasks, is the ability of F2F communication to access more than verbal (or written) utterances, and can include the use of objects and non-verbal gestures or utterances to supplement communication and improve efficiency and understanding (Have, 2007).

When looking over the audiovisual data of the three non-formal STEM activity cases, it became increasingly clear that much of the meaning behind the utterances of speakers was augmented by the use of objects or gestures, which was anticipated to a certain degree and was the reason for a multimodal approach to the data analysis. For example, there were countless instances when the participants in all three of the STEM activity cases would point to objects or to objects on a piece of paper (or the workbook) instead of saying the word for what they were referring to. This also resulted in a phenomenon of 'silences' in the data transcription when a shared understanding of the context became essential to grasp meaning from incomplete verbal utterances made by the participants within all three of the cases.

These silences are important to understand in terms of their practical importance in the transcription process and for the theoretical understanding of how shared understanding can be maintained despite seemingly essential verbal absences remaining unspoken. This awareness of how meaning can be communicated forces one to consider the sorts of information that can be lost within CMC if this nonverbal affordance within F2F settings fails to illuminate information that can go missed or even excluded within a chat context. In the three STEM cases examined here, the main observation of this trend was in the manner by which speakers in all cases failed to complete their sentences and how they often showcased instances of talking over one another to complete each other's sentences.

These two phenomena in how communication takes place in collaborative settings are not unexpected within research on group activities; however, although this does not suggest importance for the overall findings of the study, this does present an important point about the ENA method and how ethnographic understanding of an online communicative activity requires more analytical insight to properly code and understand in order to ensure information within silences and incomplete sentences can be captured and coded as representing epistemics or not. In fact, within a few short minutes of transcribing the audio data it became apparent that many of the vital words that could be assumed essential for clear and comprehensive communication were verbally absent. However, this verbal absence belies the presence of the implied word based on other modes of nonverbal communication or based on shared understanding between the speakers—which may or may not be shared by others external to the conversation.

Incomplete verbal utterances are important to understand during the coding process in terms of more than just their relationship to other complimentary communicative practices such as intonation, gaze, or mimicking gestures that provide meaning. Another important factor in communicating F2F rests with situations when silences or a lack of verbal utterances are indicative of the information being inherently understood, or not being accessible within the knowledge possessed by an individual. In these cases, there was a heavy reliance on the use of objects to help create meaning. For example, if a participant in the SDP Teacher Workshop did not know the name of a component, the ability to interact with the object could help generate understanding via a tinkering activity or the knowledge could be shared by another participant that was familiar with the object being referred to. When looking to build or assess STEM learning, or 21st century skills such as critical thinking or communication, it is important to have access to the manners by which the participants encountered opportunities to learn a new concept, apply their existing knowledge, or practice interpersonal skills. By having access to understanding and registering these communicative acts, it may become more possible to determine knowledge-sharing or acquisition factors that could be related to why STEM activities are lauded within the educational literature on STEM learning. Again, it is these sorts of interactions that are not always included in ENA due to the nature of the data used in some learning studies.

The ability of audiovisual data to afford an opportunity to see real-time learning opportunities cannot go unutilized within the ENA. When finding strong connections between 21st century skills and STEM knowledge epistemics, the ability to review the conversational data, and if needed to further access the visual data, pointed to the associations between these two groups of epistemics to be present withing the silences and situations when meaning needed to be shared within an unfamiliar context. This suggests that the F2F communication that takes place within the collaborative and project-based context of the STEM activities examined here may be an important factor in how STEM learning can be mediated, and how possible online environments can be adapted to make use of how F2F communication plays a role in knowledge sharing.

On the other hand, there can be a critique of F2F group dynamics if it results in unequal participation based on social indicators such as gender or identity, or personal indicators such as having an extroverted or introverted personality type (Chew & Ng, 2021). It was found within the data that there was often at least one participant that contributed less to the discussions taking place within the three cases. For the first case, this was s3; for the second case it was 2esm; and for the third case it was s1. Despite the limited contributions made by these participants, the affordance of ENA to not be weighted solely based on frequency of utterances allowed for their contributions to be valued accordingly with respect to the strength of cooccurrences even these few contributions produced.

This showed that although speaking less, these participants did not necessarily contribute less. This was especially true for the Mentor Training case and how 2esm showcased strong connections that when examined in the Data View revealed that key critical questions and insights into how the technical aspects of the activity functioned were not communicated by the person that spoke the most. It was this second STEM activity case that showed the most shared meaning and strong patterns of cooccurrences between 21st century skills and STEM epistemics despite the most prevalent use of incomplete sentences that were nonetheless understood between the two participants. One manner that this was accomplished was by the use of objects to aid in communication and to develop shared meaning within the context of the STEM activity. This form of object-mediated communication, and the methodological practice for recognizing indications of epistemics that are communicated with modes other than speech, is discussed in further detail below (6.5 Object-Mediated Communication in Hands-On STEM Activities).

6.5 Object-Mediated Communication in Hands-On STEM Activities

As mentioned above, much of the communication that took place was not based on verbal communication alone and presented an opportunity to reconsider the application of ENA for in-person collaborative activities. One manner that posed a challenge to ENA coding was the use of items within the environment to help with effective and efficient communication. Furthermore, the use of materials in the environment may reflect their value as components in object-based learning (OBL) instead of merely as artefact for helping in communication of knowledge or gaps in understanding.

The hands-on aspect of STEM activities is often understood to be a valuable tool and strategy for learning and for generating interest and joy about a topic of instruction. This is the hallmark of the pedagogical claims made about experiential learning and how the interaction with objects can be a mode for knowledge construction based on how the interaction with the object can foster a transformative experience for the learner (Kolb, 2015). The value of hands-on OBL is considered so important to the learning process that even online, simulation, and game environments used in learning settings attempt to ensure recreating or included a manner by which OBL can be included or virtually mimicked in terms of the existential value it provides in the process of discovery and knowledge acquisition (Urban, 2023). Within the scope of this study, there were many documented instances where a connection between a 21st century skills epistemic and a STEM knowledge epistemic were connected based on the actions or discussions that were taking place while handling or examining an object within the STEM activity learning environment.

In the first two cases, instances when objects were touched, examined closely, turned over, or otherwise manipulated in some manner was related to how the object could be used or what its function was intended for, or even to identify what the object was and the specific parameters of how it functioned. The Micro:bit was often discussed and interacted with at the same time and these instances were often found to cooccur with coded instances of critical thinking based on the discussions taking place within the window of shared meaning of a stanza. For example, it was the repeated investigation of the Micro:bit by the engineering students that resulted in their discovering that the LED matrix it had could be accessed and utilized as a light sensor, which meant that the activity could be accomplished without needing to purchase an expensive light sensor.

With respect to the Swedish teachers, they interacted with the various building materials to try and determine their properties and how they could be best-utilized for the design and functions of the vehicle. It was found that in all three cases, that the discussions about how the vehicles would be built would be overturned based on interacting with the materials and experimenting with their physical properties to better understand design, science, and engineering concepts such as balance, friction, and weight within the scope of the STEM activity. This importance of object-mediated learning (OML) cannot be overlooked and can be identified when observing a learning context such as a STEM problem-based activity.

The ENA served to elucidate what utterances were connected to the instances of object interaction and found that strong cooccurrences could be identified by the heavy edges between critical thinking, engineering, design, creativity, communication, and technology in these situations. The STEM activity cases examined here suggest that it is the act of interacting with an object, even with limited knowledge, showcased some of the more complex network segments. The importance of OBL will be elaborated on further with respect to the practice of tinkering. This act of tinkering may be the single most important factor in allowing for OML and should therefore be encouraged within STEM leaning contexts.

6.6 Cheating in STEM Activities: From Paradox to Parabola

Creativity is recognized as one of the main four "C's" in modern 21st century skills, and in project-based learning. Creativity is considered a key outcome in terms of skills development, assessment, and learning when evaluating the contribution of STEM project-based learning activities in the classroom and in the growth of students' skills and learning. However, what is meant by creativity is not always clear and the concept becomes increasingly ambiguous when various academic and professional perspectives are confounded within the development of a clear and actionable definition.

When exploring the idea of creativity and how this concept is defined and conceptualized within various research fields (e.g., social anthropology, behavioural and/or evolutionary psychology, the sociology of deviance and criminology, organizational management, and even marketing), the definitions may vary but one aspect of creativity is both acknowledged and explored. This is the duality of how creativity and its outcomes can be interpreted. Simply put, creativity can be seen as both a positive influence or a negative influence with both positive and negative outcomes stemming from both (Kaufman, 2018).

When exploring the video data from the various cases of the overarching STEM activity—including the engineering student hackathon; the mentor training session; and the SDP teacher workshop—it is possible to identify the manifestation of creativity from each iteration, and its respective participants. This was evident in the operationalization of creativity in terms of "thinking outside of the box" and how this definition carries with it the implication of rule-breaking—i.e., cheating.

In order to think outside of the box, we first have to acknowledge that the box is some set of rules or beliefs that are meant to manage and constrain the hackathon activity in terms of what artefact is created in response to the project brief, and how an individual or group undergoes actions in its creation. Thinking outside of the box implies some level of deviation from these sets of rules and beliefs that may result in some level of dissonance when considering the success in accomplishing the hackathon task.

One manner to alleviate this dissonance is to reinterpret rule-breaking as a form of creativity that stretches the boundaries of acceptable actions and outcomes within the hackathon setting. The idea that the negative outlook on rule-breaking can be mitigated by considering this action from the perspective of creativity is not uncommon, but it does introduce a dualist mode of thinking when discussing creativity within a learning setting. That is, creativity is a two-sided coin that represents both negative and positive outcomes that may be in conflict with one another.

For the sake of this research, a new analogy for understanding the nature of creativity within the three STEM activity cases explored here was employed that destroys the dualism of creativity and replaces it with a more fluid nature that reflects duality but without the antagonistic conflict. Rather than seeing creativity as a paradox, it is possible to consider it as a parabola. Rather than the duality being in conflict it shows that the duality is actually one unit that should be considered together. This eliminates the struggle and dissonance when attempting to justify cheating in terms of creativity or rule-breaking and allows it to be considered in a manner that no longer carries with it the value-laden language implicit in dualist labels that often dredge up notions of "good and bad". In a similar 'spirit' to the controversial philosophy espoused by Friedrich Nietzsche in his polemic work *Beyond Good and Evil: Prelude to a Philosophy of the Future* (1886), a parabolic vision of creativity allows for understanding this construct beyond the dualism resulting from moral consciousness and sees this construct as inherently rule-breaking but in a manner that serves the betterment of the end goal and not as undermining the order needed to conduct a learning activity.

Cheating, is paradoxical insofar as such principles are not tolerated within the traditional academic setting and carry with it potentially sever consequences that tend to discourage students for taking this course of action—cheating suggests that learning does not take place. However, within the context of the STEM cases here, cheating is not condoned and yet may be an essential aspect of how to truly integrate and apply learning concepts such as active and experiential learning. For this reason, the concept of cheating allows for a newer perspective and form, a new definition, within the cases explored here. Cheating is only paradoxical when thinking within the traditional school system and evaluating behaviours and determining expectations of how students work. When this is abandoned, a clearer and more relevant discussion about creativity within the context of cheating can be framed within STEM design and education that better links it to how progress and ideas work in these cases.

Creativity was identified within the engineering student hackathon when the engineering students delved deeper into understanding the components they were asked to utilize for the construction of a "solar-powered vehicle". Upon discovering that a light sensor, which needed to be purchased, could be supplemented or overridden with the integrated light sensors present on the Micro:bit's LED display, at least one group utilized these additional sensors to improve upon the function of the vehicle based on how the mechanical motors responded to increased light input. The hackathon group that was able to accomplish this went on to 'win' the hackathon by having their vehicle travel the furthest distance within the allotted time. Furthermore, it was this aspect that was credited with being the winning feature rather than better code or a more effective vehicle design. The students in the group acknowledged that this use of the additional light sensors that did not need to be purchased was 'cheating' and yet also a loophole since this scenario was not explicitly forbidden.

When reviewing the video data of the mentor training interaction of the hackathon, the concept of cheating was once again brought up when an engineering student that would go on to serve as a mentor for one of the SDP teacher groups noted that actions to counter possible cheating should be taken. This indicated that the mentor considered that it was possible for the group they were responsible for would also attempt to take advantages to "win" the activity and that as the mentor it was one of their responsibilities to attempt to hinder such action. In the final iteration of the non-formal STEM activity cases, the Swedish school teachers that took part in the SDP activity indicated various ways to cheat during the activity. All of these were not outright rule-breaking, but rather reflected ambiguity and creative interpretation of the limits of what could be done to gain any type of advantage in accomplishing this task.

Although it is not clearly stated and therefore cannot be attributed to the teachers' thoughts or motives, this advantage is directed at better positioning one's own group to succeed when compared to the other groups. This was evident from the data collection group jokingly wanting to keep the batteries that were present in one of the devices on the table and use them to power their vehicle instead of buying them. They did not simply find the batteries and give them back to the mentor or the non-profit organizers. Instead, they made jokes about the technical rules and that they could use them—again, it is open to interpretation why this was done and if they were hoping to draw attention to their honesty or if they were hoping to gain support to utilize this loophole.

Another identification of creativity was when another group decided to use paper that was present on the table intended for one purpose (the workbook) and use it to add design flare to their vehicle by creating a more aesthetically appealing body. One of the ways that the activity outcome was evaluated was based on how good the vehicle prototype looked, so additional aesthetic flare was one way to gain an advantage over other groups. These manifestations of rule-breaking creativity were supplemented by the results of an online questionnaire that was completed by all of the SDP teacher participants.

The items of the questionnaire asked for the teachers to indicate their level of agreement to statements according to five options on a scale of from "strongly disagree" to "strongly agree" with the middle option being "unsure". When the teachers responded to the item that asked them to rate their level of agreement to following the rules of the activity, a large majority of them responded that they either agree (41.9%) or strongly agree (41.9%) with this statement. This stands in contrast to the video evidence that displayed obvious rule-breaking even if such efforts were later corrected or the action was not followed through on. The results of the questionnaire suggest that only five of the teachers indicated that they were either unsure or disagreed that they had followed the rules, and yet at least two groups (a total of a least ten teachers) were observed to have done so. Furthermore, another questionnaire item asked the teachers to indicate their level of agreement with their use of materials in ways that were out of the ordinary. This item yielded results that were much more scattered about the various options but which revealed that roughly half of the teachers (48.4%) were unsure if they had done so or not.

Lastly, there was one item that overtly stated the word creativity, and asked the teachers to rate their level of agreement with the statement that it was more important to be creative than to find the best workable solution to the activity brief of designing and constructing a vehicle that could travel the furthest distance (measured in a straight line) within a given time when powered by a light source. The results of this item also displayed uncertainty with 32.3% of the teachers unsure if creativity was more important to them than succeeding in the activity goal and with another 35.5% of the teachers outright disagreeing about the importance of creativity over solving the problem of the hackathon. Only 29.0% of the teachers indicated that creativity was more important than creating a workable solution to the problem. Despite the results from the questionnaire, many instances of creativity could be identified as essential to creating a workable solution to the STEM activity.

The main concepts that are related to the discussion of cheating are if and how critical thinking and creativity are associated with this practice. Surely, not within a traditional educational environment, but within the STEM activities examine in this research project, it is possible to make this association based on ENA models that showcase strong general cooccurrence patterns between these two 21st century skills epistemics and information from the data that indicated cheating. Furthermore, if cheating or other limitations on the open problem-solving pathway used to address the activity is limited by rules or strict steps that must be followed, the student-centered PBL approach to learning can be compromised (Fernández et al., 2024). This is seen in the data with how the workbook ENA model does not connect with critical thinking or creative epistemics, but that the ENA models for the various group participants do when enacting the activity in their own ways.

6.7 Opportunities for STEM Learning: Connections, Check, Creation, and Code

This study does not aim to directly identify or measure any formal learning outcomes that may result from participating in the STEM activities explored here—e.g., improved knowledge about parallel circuits or how to programing using the BBC Micro:bit VPL. Rather, this research attempts to highlight where opportunities for using and/or integrating STEM knowledge and 21st century skills can be uncovered and mapped. These opportunities for learning are situated within STEM learning contexts that feature activity-based and active approaches to educational theory. The basis of many claims about the value of STEM activities for learning is based in the active and experiential nature of these sorts of learning occasions. With respect to constructivist theories of active learning, STEM activities allow for participants to build on existing knowledge and prior experiences to achieve the goal of the task.

Similarly, the foundational claims of how experiential learning is inherent within STEM activities is premised on how real-world occurrences and problems can be used to synthesize educational content with the activity outcomes. In both of these ways, STEM activities provide such opportunities by having participants take part in key aspects of STEM such as the integration of various subject theories and knowledge, together with the practical act of building, creating, and testing their solutions, which is not unlike how problems are addressed in the real world.

Unlike formal educational settings and their standard applications of summative assessment, a correct answer is not sought and is not essential to provide learning opportunities in a STEM activity. What can be found within the analysis of these cases, is that even if learning is not measured, it is possible to see how knowledge and skills are connected in the ideas and actions of the participants. This showcases the use and possible development of knowledge and skills. It can be argued that the point of possessing knowledge and skills is to put them to use and to integrate both skills and knowledge into deeper understandings as more skills and knowledge are discovered and practiced. For example, it is possible to encounter several university students that fail to link their secondary-school algebra classes with a post-secondary lecture on linear regression analysis, which shows the conflict between having knowledge and skills and not recognizing their application outside of one particular school setting. STEM activities offer one avenue to shift the focus from what a student knows or learns to allowing skills and knowledge to be applied, reflected, shared, and even constructed.

This research project brings to light this performative aspect of STEM learning and STEM education with respect to some of the key features that define STEM pedagogy. For example, this research generates evidence that the design and delivery of a STEM activity requires opportunities for learners to make connections between their various sets of subject-based knowledge and to help improve their social and modern technical skills to put this knowledge to use in solving realistic and relatable problems. By looking at the sorts of verbal and nonverbal interactions taking place within the examined cases, it is possible to identify what laudable qualities these cases demonstrate in upholding the positive claims made about STEM learning in educational and academic circles.

By combining the analysis of all of the STEM activity cases, it is possible to conceptualize these activities as a model of STEM learning based on the processes that took place between and among the case participants. This model is not a definitive model of STEM learning, but does outline how the connections made between STEM knowledge and 21st century skills epistemics are related to the structural elements of the design and pedagogy of the STEM activities examined over the course of this research project (see Figure 40).

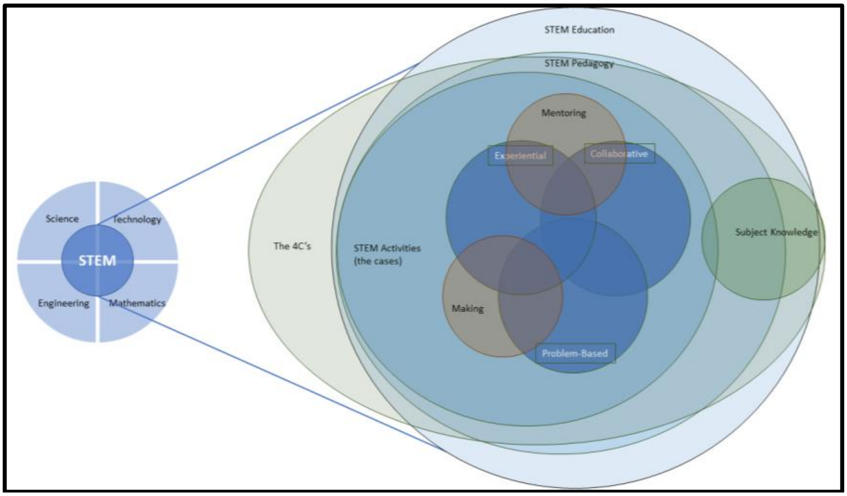

Figure 40: Relationship of STEM Activity Components

The cases explored in this study highlight some keywords regarding how active and experiential learning theories can be implicit in their very design in terms of providing more "meaningful" learning opportunities than those provided within traditional classrooms using traditional teaching instruments and methods. The learning opportunities identified within the three engineering hackathon iterations were instances where the participants were able to *tinker*, *make*, *design*, and *code*. All of these instances presented verbal confirmation of using existing knowledge to solve the problem provided to them. At the beginning of this research, it was not clear if the STEM activities would include aspects such as these, and although this research is limited by the small number of cases and a lack of diversity in what sorts of STEM activities could be observed, these cases still provide a good framework that is comparable to other STEM activity designs. It is important to remember that this research does not aim to generalize about STEM activities overall, and is instead focused on identifying communicative and interactional information that can be used to anatomize and frame the activities observed within the scope of the study based within an understanding of STEM learning theory and practice.

The overall structure of the activities allows for the learning opportunities to be structured based on the various segments of the STEM cases examined here. Although the structure and learning opportunities are unique to these cases, it is possible to see how this model can relate to other STEM activity contexts in more general terms. The organization of how the opportunities for learning within the three STEM activity cases examined here can be situated and identified as based on the four themes outlined in more detail below: Connections; Check; Creation; and Code.

6.7.1 Connections (Bridging Knowledge and Finding Key Moments)

Connections are meant to signify the integration of knowledge within the activity and finding associations with existing knowledge within the activity. One of the ways that this was found within the data was when direct references were made by the engineering students, especially during the mentor training case, to what took place during the hackathon. Within the ENA networks, an investigation of the cooccurrences between STEM epistemics during the early stages of the activity (i.e., planning and organizing), when it was expected that more 21st century skills epistemics would be identified, found that these early stages often showcased overt references to past knowledge and how to apply that to the current situation. The connections that are made between the stages of the STEM activity iterations can point to an opportunity to engage in experiences to allow participants in a STEM activity to attempt to consider their existing knowledge prior to engaging in the activity. When looking at these cases, this reflection seems valuable at the start of the activity to establish a point of shared reference between the participants, or to streamline the planning stages of the activity by not having to "reinvent the wheel" each time the activity is undertaken. This identification of key moments in the activity that could relate to previous experience can be another way to interpret this finding.

6.7.2 Check (Experimentation and Testing Ideas)

The concept of check is meant to highlight the role of experimentation and how testing out ideas could be linked to connections in the networks between knowledge and skills epistemics. For example, critical thinking cooccurred with the STEM epistemics and was associated with discussions about testing ideas or testing how the mechanical features of the activity functioned. All three of the cases showed strong and more complex interactions when discussions about finding problems and working out solutions were being undertaken. Rather than the simpler connections that were made between the STEM epistemics during the structured activity of building the electronics (especially in the second and third cases), there were more links between 21st century skills and STEM epistemics during stages of evaluating existing problems, or potential future problems, and solutions that took place during the course of the activities. By allowing this section of the STEM activities to be elaborated upon, or to scaffold these investigations as was done by the mentor in the third case when the amplifier was being tested and when the direction of the wheels needed to be verified, it is possible to not only allow for greater practice of 21st century skills, but to build STEM knowledge that may be applied but not acknowledged in a manner that results in a concrete learning opportunity.

6.7.3 Creation (More than Just Making)

Within the literature about STEM education and STEM learning there is often a reference to *making* as a key component of the hands-on "learning by doing" mantra. Interest among educators, policy makers, curriculum developers, and educational administrators to incorporate maker-centered learning experiences is based on the capacity for *making* to increase proficiency and interest in STEM subjects (Clapp & Jimenez, 2016) while also fostering creativity, computational thinking (Huang et al., 2024), and social interaction between STEM activity participants (Y.-Y. Liu & Iversen, 2022).

However, within this study the overarching concept of *making* seemed reductive and only captured one facet to an ideation about creation as a procedure that begins with ideas and ends with artefacts. This statement originates from reflection on the process coding for the *make/maker/making* construct within this case study and how a broader definition of making could include anything from the design to the fabrication and later testing of prototypes or electronic builds. Because of how this concept can be used to encompass more than just the physical and tangible practice of building something, it becomes an aspect present within various stages of a STEM activity and results in a loss of distinction in the appropriate categorization and segmentation of data for ENA to visualize more discrete relational patterns.

When *making* is considered to encompass all aspects of the creative fabrication process, this one construct becomes meaninglessly pervasive in a dataset about STEM. When considering how the SDP workbook segmented the whole of the SDP teacher workshop to draw attention to activities such as design, coding, connecting electronics, prototyping, testing, and troubleshooting, it became obvious that making is a part of the whole of the workshop. In order to make sense of *making*, and to align this concept with the design and delivery of the three STEM activity cases examined in this project, *making* became only one stage of a process that was termed creation. Creation, within the context of these three STEM cases, allows for *making* to become one part of a larger process that also isolates *tinkering* and *design* as explicit and important parts of the hands-on learning experience within these STEM cases. This distinction between making and other characteristics of STEM learning is not too different from other proposed models of maker education that also distinguish making from features such as tinkering and engineering (Heroman, 2019).

Tinker

Touch is one of the five sense we use to explore our environment and understand the things we find in it. Tinkering is one way that we use our sense of touch together with our four other senses when engaged in hands-on learning—i.e., OBL and OML. Within the STEM learning framework, the manners by which professional scientists and engineers think and act when faced with challenges and real-world problems are reflected in how children and curious individuals explore materials and their physical properties, try to figure out how things work, deconstruct or combine things, and use tools to build or make things (Heroman, 2019). This is how the process of tinkering is defined, understood, and witnessed within STEM education (Heroman, 2019). Within the STEM activities examined in this study, it was possible to code for tinkering when observing how participants would interact with materials before formally engaging in the making of artefacts such as a program code, a body for the vehicle, or combined electronics used to power the vehicle.

Design

When looking over the ENA models for all three of the cases, the engagement with how to build the car produced the strongest connections within the 21st century skills epistemics, but did not always create strong connections with the STEM epistemics as well. The simple fact that the discussions about how to build the car can have implications for STEM subject matter can go overlooked based on the commonplace language that is used to discuss this topic. In the first case the design aspect saw the engineering students make many more connections between 21st century skills and STEM knowledge epistemics, which did not exist during the SDP teacher workshop case. The design of the vehicle was essentially the same practice in all three cases and the knowledge and skills of the participants was the deciding variable in creating the epistemic frame about how many science or engineering concepts would be summoned to explain or understand this exercise. In order to create more integration for STEM and to also create more STEM cooccurrences with the 21st century skills epistemics used in the collaborative exercise of designing and building a vehicle model, this segment of the activity can be one instance where the participants can be asked to reflect more critically on how the functions and structure of a vehicle can be more technical and scientific.

Make

When the ENA networks were examined from each of the three STEM activity cases, the importance placed on the different stages of the activity was revealed based on the patterns of what epistemics were most channeled in the discussions. What resulted was the need to see the making that took place in the activity as a more complex process that spanned the entirely of the STEM activity, but which manifests in different practical acts at each stage. The network, if making was inclusive of tinkering and designing, became less informative despite showing stronger connections. What this meant is that making needed to be re-defined into aspects that reflected the stages of the making process within the scope of these cases. Making, as defined here now is only the practice of putting something together only after one has tinkered with it and/or undertaken some actions or conversations about the design elements that are guiding the making. Making is the connecting of the electronic parts, and the construction of the vehicle body including the moment the electronic components are included, and the act of writing out the computer code once algorithmic or computational thinking have taken place.

What this revealed is that making can sometimes be a process that is difficult to understand in terms of 21st century skills and STEM knowledge epistemics, because in comparison to design and tinkering, there was less discussion or other interactions taking place when just making. This supports the position taken here that making should be subdivided into its constituent parts and summarized as the process of creation. When done like this, rather than seeing making as a large segment of the STEM activities with many strong and complex connections, it is possible to isolate the exact details of making that can be more respective to learning interventions than can the simple act of putting something together. For future consideration, the making aspect can be a good opportunity for reflection to better understand and integrate the various STEM fields that are enacted or manifest in the overarching creation process.

6.7.4 Code (collaboration = 0 if coder = = 1)

Learning a coding language and learning how to code are not one and same. A simple analogy to highlight the distinction between the two would be to suggest that although one may know how to speak a language, they may still lack the skills to be a truly eloquent or persuasive orator. Perhaps another way to contemplate this distinction is to reflect on the differences between the ability for most people to write a code in terms of an algorithmic sequence, but how not many people are skilled in the coding practice to produce truly idiomatic programming.

Coding during the various iterations of the STEM activity cases was an integral and practical exercise that required participants to translate directions to a computer language and to think computationally to plan and correct the code written to control the various components of the electric vehicle that the participants were tasked to create. However, when looking over the networks, it was found that the fanciful description of what programming is within the scope of this activity proved to have very little complexity or strong connections with either the STEM or 21st century skills epistemics. However, coding was one of the key themes of the SDP thematic unit box, which was focused on the use of the BBC Micro:bit in service of the Swedish programming curriculum.

This suggests that greater attention needs to be placed on how to better incorporate a collaborative aspect to coding, which in all three cases was a predominantly solitary and silent activity—especially when having to exclude the screen recordings of the PLE from the engineering student hackathon case.

Also, despite the argument that coding is a mathematical and logical practice, nothing in how the participants discussed the coding activity reflected these concepts. What was expected but missing was a discussion that reflected stages in algorithmic and computational thinking that generate computer code by breaking down the problem, or identifying common code tasks, or even generating flowcharts or pseudocode. Encouraging a more collaborative coding process for STEM learners, and capturing evidence of coding processes for future educational research, may require the use of more refined tools for collaborative or pair programming (e.g., GitHub), or rethinking the design of coding workflow to increase collaboration or code quality (Demir & Seferoglu, 2021).

At the moment, and based on the methods used in this research project, coding was more indicative of a temporal stanza-based data segmentation associated with few cooccurrences represented among the epistemic codes. This result, however, does not validly represent the learning opportunities that the practice of coding may introduce to a STEM activity context. However, this does bring to light the possible disconnection between what knowledge and skillsets are associated with coding practice, and if these aspects are present in all coding learning environments or activities.

6.8 The Role of Mentors: Teaching STEM and Learning 21st Century Skills

The discussion about the role of mentors is based on the findings that the mentor or instructional participant within each of the cases produced a network that was often different to those of many or all of the other participants, and that this difference was often at a statistically significant level. Not only was there a difference between the networks of the mentors and the activity participants, the ENA made it possible to identify the nature of the connections created between the epistemics that set these networks apart.

For all of the cases, the mentor was taking on an instructional role rather than directly participating in the activity itself and the conversational data of the mentors were most often in response to questions or the need for clarifications being brought forward by one or more of the participants. In the first two cases, the mentor was a staff member of the non-profit and in the third case the mentor was an engineering student. All of these mentors showcased networks with stronger relational ties among the STEM epistemics, and it was often the case that discussions with the mentors communicated new and critical information related to understanding the scientific or technical details of the activity, or parts of the activity. For example, the non-profit staff members provided the engineering students taking part in the hackathon with a better understanding of how to access the light sensor functions of the Micro:bit LED matrix. Also, in the third case the engineering student was able to help the teachers to understand the implications of the amplifier within either a direct or parallel circuit.

The role of the mentor functioned as mainly a resource for STEM knowledge, which served the needs of the participants, but limited the implications of the STEM activity serving as a way for the engineering student to practice and refine 21st century skills. In order for engineering students to gain more practical industry skills, the STEM activity cases examined here would have to consider how the role of the mentor can be refined to serve the needs and interests of the mentor and not just the participants.

For example, when the teachers in the third case seemed to be indecisive about the role assignments, the mentor was able to use humor to help the teachers complete the role assignments. With the exception of this example, and the possible similarity with the non-profit and the engineering student mentors tracking the time of the activity to keep the groups on track, the role of the mentor was relegated to helping with solving technical issues or filling gaps in STEM knowledge regarding the electronics or coding segments of the activity.

6.9 Answering the Research Questions

The overarching goal of this research project is to look inside the black box of STEM activity learning. This goal is intended to provide real-time evidence for claims about STEM learning and its association with the practice and development of both STEM subject knowledge and 21st century skills skills such as critical thinking, creativity, communication, and collaboration (i.e., the 4C's). This overarching goal manifests in distinct research questions identifying what is taking place within the STEM activity cases, and how the interplay of knowledge and skills differ between cases and subcases. Furthermore, other research questions look to identify how this interplay of knowledge and skills can be used to reflect the underpinning learning theories often attributed to STEM pedagogies (e.g., problem-based learning, experiential learning, and collaborative learning), and how making and mentoring contribute to the learning environment.

When presenting the answers to the research questions, it is possible to combine the four questions according to their related understandings of the whole STEM activity context. The first research question and the last research question focus on the sorts of inputs that are designed into the learning environment and can be understood together in terms of how these inputs influence processes and interactions over the course of the activity. The second and third research questions are more closely associated with the interpretation of the epistemic network models generated by the interplay of STEM subject knowledge and 21st century skills. These two questions combine to provide more understanding with how the interactions and processes can be interpreted within the context of learning STEM or practicing 21st century skills. The second and third questions are, therefore, associated with understanding how the conditions for learning can be investigated with respect to the outputs of a STEM learning environment.

Regardless of how the questions are divided based on the focus on inputs or outputs, both sets of questions rely on understanding and interpreting the words and actions of the participants based on how these two factors manifest either STEM subject knowledge or 21st century skills. In order to investigate these claims, the analysis focuses on uncovering interactional patterns between various factors unique to the selected cases—these selected cases being identified as instances of non-formal STEM activities. The cases examined here resulted in findings that provide more clear examples of opportunities for learning that are present within the processes and interactions taking place over the course of the STEM activities. By identifying these conditions for learning, it becomes possible for future research to attribute reported improvements in subject knowledge or the use of 21st century skills to these conditions for learning when determining the effectiveness of STEM activities with respect to measured learning outcomes.

Strictly speaking, the conditions for learning help to understand the contributions of inputs into the learning environment, and these conditions for learning do so by highlighting instances where the strengths in the relationships between both STEM subject knowledge and 21st century skills are significant. This results in an integrated understanding for how the knowledge/cultural community created by the STEM activity participants makes use of the various inputs in the service of the specified outputs.

Below (p. 181) is a representation of the components of the STEM activity learning environment based on the three STEM activity cases (see Figure 41). This figure is a visual summary of the key components of the non-formal STEM activities examined in this research project. This visual summary shows how these components can be integrated into a simplified diagram that showcases the importance of the process and interactions uncovered in the analysis and how they are 1) associated with shaping the relational analysis of the STEM subject knowledge and 21st century skills outputs; and 2) associated with the closing of the analytical loop in understanding the inputs in relation to derived conditions for learning. What is required to enrich this model is to present the findings of this study with respect to illuminating the black box where the processes and interactions shape the conditions for learning specific to the non-formal STEM activities examined in the research project.

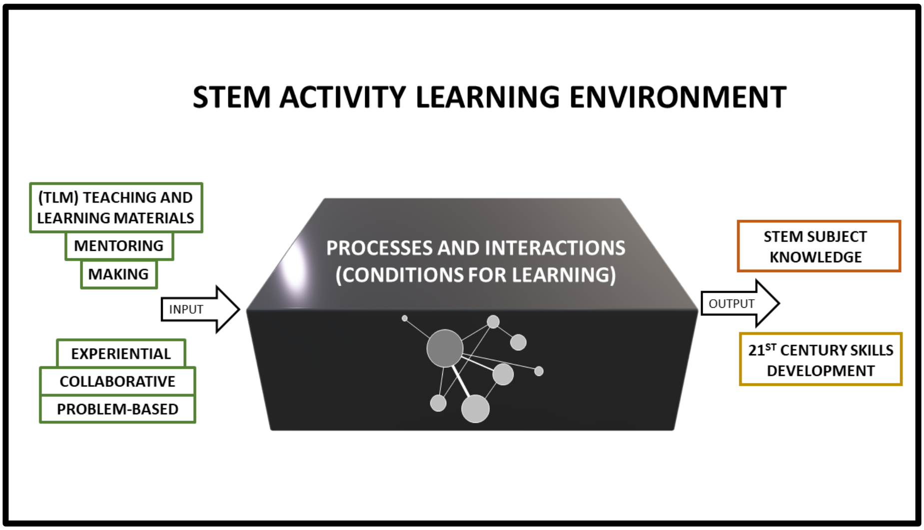

Figure 41: The Learning Environment of the STEM Activity Cases

6.9.1 Illuminating the Black Box of STEM Activity Learning

Illuminating the black box of STEM activity learning is anticipated to generate better understanding about what took place within and over the course of three STEM activity cases. This aim was driven by a curiosity to better establish the relationship between pedagogical inputs and educational outputs via the processes and interactions taking place in real-time between the various human and non-human actors within the cases. The domain of the activity that sits within the real-time duration of the cases is termed the black box. This black box conceals what takes place between the inputs of the cases and the outputs that are attributed to them. By analyzing the verbal and non-verbal data collected via video recordings, it is possible to present one possible interpretation for what takes place in the black box of STEM learning activities, and specifically what took place within the three STEM activity cases examined in this research project (see Figure 42).

This investigation into the black box of STEM learning seeks to identify and better understand the sorts of processes and interactions that take place in the learning environment. Identifying and understanding these two facets to what takes place over the course of the STEM activities, between and among the various human and non-human participants, allows for direct evidence to be attributed to learning theories for STEM activities.

The use of ENA examined these questions using, primarily, relational models representing how epistemics for STEM knowledge and 21st century skills cooccurred within each of the cases and between each of the case participants.

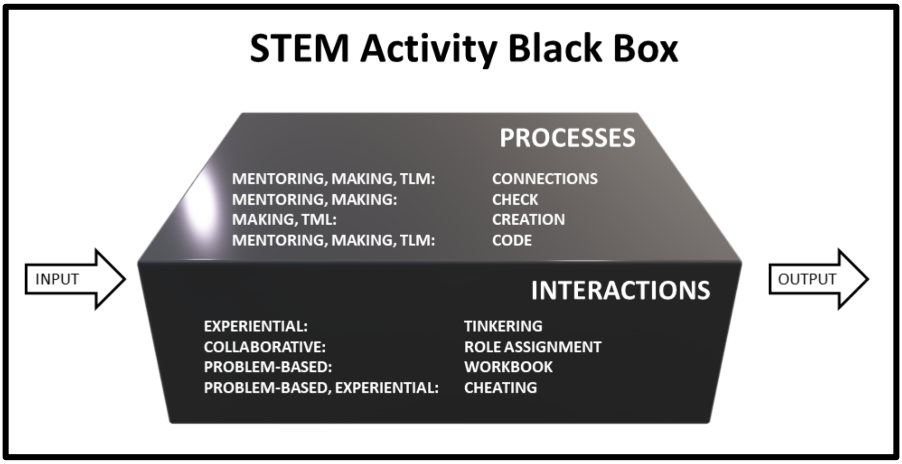

Figure 42: The Black Box of the STEM Activity Cases

These relational models, and the analytical space they are situated within, represent the knowledge/cultural community of the particular cases as defined by what the participants in the activity said and did. Understanding this participant-constructed community, and associating it with an understanding of the activity from a theoretical level, allows for processes and interactions to become identified and classified.

However, without looking at the processes and interactions in detail, the STEM activities reflect only vague references to the theoretical elements of the learning environment. Below is a more detailed discussion about the processes and interactions taking place within the STEM activity black box.

6.9.2 The Conditions for Learning (Question 1)

The conditions for learning are situated within the STEM activity black box and were gleaned from examining the relational models and referring back to the source data in both transcribed form and the coinciding audio-visual clips. By closing the analytical loop and bridging the relational models with the words and actions of the participants, a more refined understanding of the STEM activity black box becomes available. As a result, theoretical learning concepts such as experiential learning, collaborative learning, and problem-based learning can be replaced with more specific conditions for learning based on interactions and processes, and the inputs into the learning environment can be linked with the processes and interactions they facilitate (see Figure 42).

The sorts of interactions taking place between participants and between the participants and the environment are: 1) the act of tinkering to reflect hands-on and experiential learning; 2) role assignment and how that frames the collaborations of the participants; 3) cheating and how this stretches the boundaries of problem-based learning; and 4) referral to the activity workbook as establishing guidelines and information for solving the problem-based activity.

The processes that reflected the knowledge/cultural community constructed by the participants showcase how the particular inputs into the learning environment translate into processes such as: 1) connections; 2) check; 3) creation; and 4) code. The processes of *connections* and *code* bring together all three of the inputs (mentoring, making, and the TLM). The *check* process makes use of the mentoring and making inputs of the activity design while the *creation* process makes use of making and the TLM.

These processes provided more than ways to activate the various inputs of the learning environment. When investigated during the analysis, a critical analysis of these processes allowed for more critical investigation of the conditions for learning, and how they may be improved upon to design STEM learning activities better able to achieve specific learning outcomes associated with one, some, or all of the processes present in the learning context.

The conditions for learning uncovered within the three STEM activities aligned well with the sorts of STEM learning frameworks often put forward in the literature with respect to the use of experiential, collaborative, and problem-based approaches to learning. The cases showed that these aspects of the theoretical framework were indeed present within the activities during their delivery and that these aspects of the STEM learning framework were associated with opportunities for learning of STEM knowledge via practices related to 21st century skills such as communication, collaboration, critical thinking, and creativity.

Although this research was guided by attempting to address the limits of methods that failed to capture real-time data about what takes place over the course of a STEM activity, it is clear from the results that the assumptions about the contributions of the pedagogical theories that lay at the foundations of STEM activity learning can be linked to the possibility of improved learning outcomes based on their association with providing clear opportunities to learn STEM and 21st century skills.

When looking deeper into the sorts of discussions and actions related to the stronger connections between the STEM and 21st century skills epistemics, it was further possible to understand more clearly that what made experiential learning effective was related to the concept of tinkering, and that the ability of the participants to break the rules of the activity allowed for opportunities to apply more creative and critical solutions to the problem. The key feature to the findings, and their support for these cases in upholding existing research and claims about why STEM activities are associated with improved learning outcomes, is that a contextual understanding of what the broader concepts of experiential, collaborative, and problem-based mean within a specific STEM case can yield a clearer pathway to identify and utilizing the opportunities to grow and apply skills and knowledge.

In order to further the discussion regarding the processes related to the conditions for learning, the following section incorporates more details about the pedagogical inputs of making and mentoring into the knowledge/cultural communities of the STEM activity cases.

6.9.3 Making and Mentoring (Question 4)

The cases showcase some conditions for learning that are typical of STEM learning design, but also some factors that take a slightly unique perspective on the pedagogical design of the cases—for example, the mentoring provided by engineering students rather than having a traditional instructor, and the situation of the activities within a makerspace environment.

Not all STEM learning or educational activities have the components of making and mentoring. Making is a key aspect that is often mentioned in the literature when referencing the hands-on, practical, and experiential-based learning features of STEM activities. However, making is not necessarily or always a part of STEM education, especially in contexts where access to specific learning materials can be limited by the practical constraints of a traditional educational setting.

One of the ways that these cases contribute to understanding these two components is how the cases conceptualize these two elements. Making is linked to the use of makerspaces, and mentoring is done using engineering students from local higher education institutions. This research question looks deeper into how these two deliberate inputs of making and mentoring into the learning environment translate into learning processes and interactions. An interesting conclusion to note is that the differences in how the verbal and nonverbal contributions of each participant shapes how STEM knowledge and 21st century skills are related within the enactment of the STEM activity does not impact on being able to find similar trends in how making and mentoring contribute to the learning opportunities within each case.

The mentoring provided in each activity was set apart from the participation in the activity and was framed within an instructional role that served to provide knowledge rather than guidance to the participants. The mentoring factor of the STEM activity cases was examined by looking not only at how the network models for the mentoring participants differed from those of the learner participants, but more specifically in identifying how they were different in terms of possible contribution (i.e., input) to the learning environment of the STEM activity cases. The mentors showed more connections between STEM epistemics than the learning participants, which highlights their roles in bringing knowledge constructs into the activities. This suggests that the mentors are influencing the overall epistemic frame to represent STEM knowledge constructs that would otherwise not be present if the mentor were to be excluded from the ENA. When looking into the source data associated with the STEM cooccurrences within the mentor network models, it was more likely that these cooccurrences took place during instructional conversations (e.g., answering questions) about the technical aspects of the STEM activity and are more indicative of gaps in STEM knowledge on the part of the participants. However, by introducing knowledge to fill these gaps, there is justification for using ENA to see what connections are made among the actions and words of the participants in and around the utterances of the mentors. It is possible to define the role of the mentors as injecting STEM knowledge constructs into the STEM learning environment, which provides an opportunity for the participants to form connections around this new knowledge within the verbal or non-verbal utterances they make in response.

However, if the goal of a STEM activity that utilizes engineering students as mentors is meant to benefit the mentors by helping to develop their 21st century skills, it becomes important to refine the role of mentoring to better incorporate the practice of 21st century skills alongside their knowledge contributions. This is one aspect of the cases that can be improved upon in order to allow for the role of mentoring STEM activities to also provided more opportunities for engineering students to practice and refine their professional skillsets. From the findings of this research project, the mentors often showed stronger connection between only STEM epistemics and weaker connections among STEM knowledge and 21st century skills epistemics.

The role of making proved more complicated to isolate in light of how broadly this concept applied to almost all sections and segments of the STEM activity cases. This is not unexpected due to the context of the activities being situated within a makerspace environment. What this investigation uncovered was the value in deconstructing the concept of making in order to bring to light how the design and tinkering elements of the activity contribute as well. This refinement found that making (strictly defined as combining all the aspects of the activity to produce a final produce that featured design and technology) did not reveal very strong or complex connections with the STEM and 21st century skills epistemics when compared to those found in design and tinkering. The most crucial finding is that the act of tinkering is perhaps the most vital aspect of the STEM activities with respect to presenting an opportunity to learn STEM knowledge in combination with 21st century such as creativity and critical thinking.

6.9.4 Inputs, Processes, and Interactions (Questions 1 and 4)

The first and last research questions can be combined to exhibit an integrated understanding of the STEM activity inputs and the conditions for learning that occur over the course of the activities. The first research question seeks to identify the conditions for learning within the activity and is answered by articulating the processes and interactions taking place in real-time over the course of the activity. The last research question delves deeper into the roles of making and mentoring; these two inputs into the learning environment are associated with the conditions for learning that were identified over the course of the investigation of the cases.

When taken together, the first and last research questions formulate one possible understanding for how the inputs and conditions for learning manifest within the learning environment of the cases examined in this research project. Furthermore, combining the inputs with the findings of the analysis and the resulting conditions for learning showcases how inputs can translate into processes and how they can drive particular interactions (see Table 7). For example, Table 7 reveals that the process of *Connections* was found to contain evidence for all of the tangible and intangible inputs, which suggests that this process is supported by various dimensions of how the STEM activities were designed. The *Role Assignment* interaction was associated with evidence for mentoring and collaborative inputs, and perhaps shows the limited nature of how this design element contributes to generating or formulating conditions for learning within the context of the STEM activity cases included in this investigation.

However, a simple numerical count for how many of the conditions for learning are associated with the various inputs only allows for understanding how the inputs translate into conditions for learning within the black box of the STEM activity cases. This does not imply an interpretation for which of the inputs are the most effective for STEM learning. Rather, this relationship between the inputs and the conditions for learning provide information for how learning may manifest over the course of a STEM activity. This evidence helps to address some of the concerns about STEM literature that outlines inputs into a STEM context in a manner that loads them with explanatory value, but lacks the clear association with how these inputs contribute to learning outputs. This analysis provides one example of what sorts of interactions and processes are associated with a selected set of inputs designed into the learning environment of the cases examined in this case study.

The focus on the first and last of the research questions implies an examination of the first half of the input/output model used to represent the STEM activity cases. The first half of this model focuses on the black box in combination with the inputs of the learning environment (see Figure 43). The inputs into the learning environment are listed as both the tangible and theoretical factors that are designed within the pedagogical construct of the STEM activity.

Table 7: Inputs and The Related Conditions for Learning

Conditions for Learning	Inputs (Tangible)			Inputs (Theoretical)		
	Mentoring	Making	TML*	Experiential	Collaborative	Problem-Based
Processes:						
Connections	✓	✓	✓	✓	✓	✓
Check	✓	✓		✓	✓	✓
Creation		✓	✓	✓	✓	✓
Code	✓	✓	✓	✓		
Interactions:						
Tinker	✓	✓	✓	✓		✓
Role Assign-ment	✓				✓	
Workbook			✓		✓	✓
Cheating		✓		✓		✓

*TLM (Teaching and Learning Materials): 'Thematic Units' in the form of tinker boxes/maker kit.

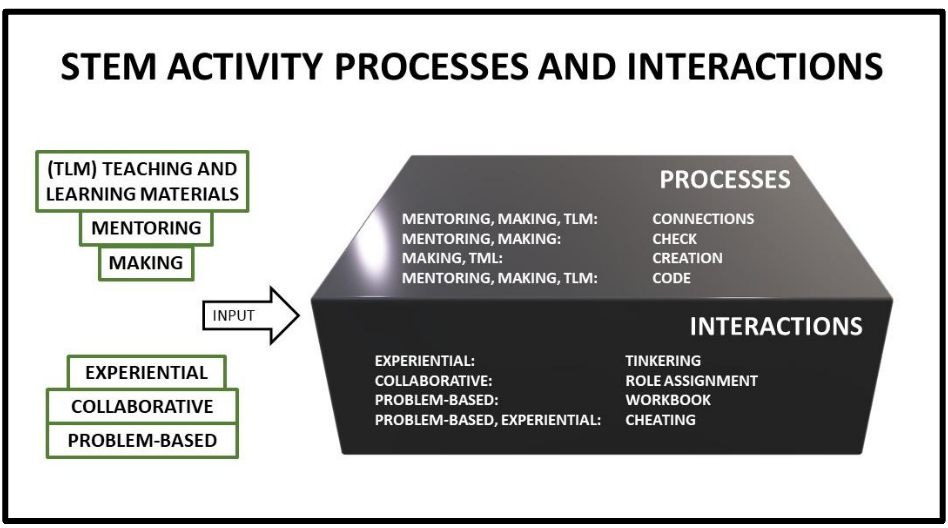

Figure 43: STEM Activity Inputs and Related Processes and Interactions

The tangible inputs of the learning environment include the activity setting, the sorts of artifacts placed into the environment that can be interacted with and utilized, and the persons present within the context that serve to instruct or guide the activity. These material inputs translate into: 1) the makerspace context where the activity took place (MAKING); 2) the teaching and learning materials provided in the form of a 'thematic unit' containing various electronic components, tools, the BBC Micro:bit, and in two cases a workbook (TML); and 3) engineering students or non-profit staff organizers that serve as the instructors (MENTORING).

The intangible inputs are the learning theories that underpin the design and implementation of the STEM activities. These theoretical inputs include: 1) the use of hands-on and reflective processes to execute the activity objectives (EXPERIENTIAL); 2) the group-work and role assignments guiding how the participants tackle segments of the activity (COLLABORATION); and 3) the use of an open-ended, real-world, problem to teach about STEM subject matter (PROBLEM-BASED). These learning theories are situated as design inputs into the learning environment, but also associated with the interaction and processes within the black box. By shifting the learning theories away from being designated only as inputs into the learning environment, and instead associating them with the conditions for learning within the black box, it becomes possible to create more concrete understandings for how these learning theories can lead to learning outputs based on processes and interactions influenced by inputs into the educational context.

6.9.5 ENA Relational Models and Case Comparison (Question 2)

The use of ENA examined questions about STEM learning using, primarily, relational models representing how epistemics for STEM knowledge and 21st century skills cooccurred within each of the cases and between each of the case participants. These relational models, and the analytical space they are situated within, represent the knowledge/cultural community of the particular cases as defined by what the participants in the activity said and did.

Understanding this participant-constructed community, and associating it with an ENA analytical space signifying the manifestations of STEM knowledge and 21st century skills, allows for a way to investigate each of the cases with specific reference to the desired knowledge and skills outputs intended to come out of participation. Furthermore, this investigation allows for comparison between the cases, and between the participants within each group case, to isolate factors in learning and skills development at a more individual and nuanced level.

The value of adding a comparative aspect to understanding the three STEM activity cases, and their various subcases, better identifies how every STEM learning environment can be designed the same, but yield different results based on how the participants engage with the activity and each other. This investigation into the similarities and differences between the knowledge/cultural communities generated by the participants can have interesting ramifications for understanding how learning can or cannot take place within a STEM activity context.

The ENA allowed for quickly identifying trends in each case in order to compare what the networks show about the connections between subject knowledge and 21st century skills. What was interesting to discover is that despite the three cases featuring essentially the same theme and problem, the networks that reflected the epistemic frame for each of the activities still produced informative distinctions from one another. Primarily this was based in how the overall patterns of connections and cooccurrences in each case positioned the coded epistemics in unique ways within the analytical space displayed by the ENA webtool. This suggested that the discussions and actions for each case were not the same despite the overlap in themes and participants among them.

The first case with the engineering student hackathon, could be described as having stronger links with STEM concepts based on how the participants communicated with each other, while the second case of the mentor training could be seen as having more varied connections with the STEM and 21st century skills such as critical thinking and collaboration.

The first two cases had engineering students as participants, but different discussions took place despite the second activity being closely related to the hackathon case. The design of the second case took the focus away from only a STEM-related hackathon and introduced the need to consider how the participants would conduct the activity serving as mentors, which could account for the increased representation of cooccurrences with STEM and 21st century skills epistemics.

The analysis of the third case took on a unique approach that incorporated the activity workbook into the analysis due to its perceived importance within the verbal and non-verbal communications taking place in the case. This workbook was not present within the first case, and only introduced in the second case in a peripheral role. This analysis compared the expected format of the activity as presented in the workbook and how the activity unfolded by the words and actions of the case participants—the Swedish school teachers.

The comparison of the expected knowledge/cultural community of the teacher workshop case based on the workbook, and the knowledge/cultural community generated by the participants were not the same. The two networks of the third STEM activity revealed much weaker connections regarding the STEM epistemics among the interactions of the teachers than the information in the workbook would suggest could be present. This introduced questions about the role and influence of the TLM in the STEM context in terms of the information it provided versus the structure it imposed.

When using the information from the epistemic frames of the ENA, it is possible to identify several key trends in how the cases compared. Each case, and each sub-case participant, produced unique networks showcasing connections between knowledge and skills epistemics that were heavily determined by thematic segment of the activity they were assigned to. Fewer connections with technology were made by the participants that did not build the electronics or take part in the coding activity—this was most obvious in cases one and three. The role assignments may have made for a more manageable accomplishment of all of the tasks included in the activity, but this also resulted in framing what skills and knowledge could be accessed or used by the participants within the constraints of their specific tasks and objectives.

6.9.6 Closing the Analytical Loop of STEM Learning (Question 3)

The anatomy of the cases in terms of their relational ENA models provided information for uncovering the conditions for learning and possible sources for the differences found within the various cases. This was done by using the network models for each case or subcase to isolate evidence that could potentially yield interesting findings when examined closer and deeper. This deeper analysis uses the network data to locate sets of cooccurrences and their associated source data (e.g., transcribed conversations or video clips).

Using the Quantitative Ethnographic method requires a closing of the interpretative loop between what the models communicate about the cases, and how this information can translate into understanding STEM learning. The most obvious contributions made by the ENA models were in helping to provide information to derive the learning conditions by associating network distinctions that could be linked back to source data, which was done by highlighting interesting patterns in the networks and reviewing the selected data associated only with that pattern. The ENA models made it possible to examine the connections made in each case based on the raw data that the connection was based on. This allows for a better way to identify what the participants said and did in order to generate the connections featured in the ENA network models.

Often, it was the strongest connections that were investigated deeper to understand what occurred or what was discussed, and that could be associated to the use of STEM knowledge and 21st century skills in combination with one another. The general finding was that the use of ENA was able to bring to light the strengths and weaknesses of the design of the STEM activities in how they reflected STEM learning theories. For example, the role assignment of the participants and how that framed the sorts of discussions and actions available to individual participants can be applied to understanding learning outcomes in greater detail in STEM educational settings that also utilize groupwork or other segmented task assignments. Overall, the general finding is that learning can take place in many different ways despite the context and activity being similar.

What this provides for understanding STEM learning is counterintuitive insofar as the specific findings of such a limited case study analysis can actually provide more generalizable information about learning contexts that are vastly different but that can have similar design elements at their core. What the findings of the ENA allow for is a method to generalize about abstractions of specific learning contexts that are informed by the individual processes of learning in collaborative settings where the sharing of knowledge and displaying of skills are the very fabric of the learning environment.

6.9.7 Outputs, Knowledge, and Skills (Questions 2 and 3)

The second and third research questions focused on the interpretation of the relational models generated by the ENA webtool. This interpretation built on understanding the anatomy of each case in terms of the connections formed between STEM knowledge and 21st century skills constructs, and incorporated a comparative aspect to the interpretation. The network comparison helped to identify how the contributions from the participants' words and actions shaped the knowledge/cultural community of their respective STEM activity case. Furthermore, the last interpretation of the network models involved looking into the source data that was associated with information from the network models that stood out in the analysis as important for the aims of this research project—i.e., understanding STEM learning. By bridging the interesting findings of the ENA and the raw data underpinning them, it was possible to close the analytical loop and to attribute more nuanced explanations for how learning could take place within the cases and result in outputs related to improved STEM subject knowledge and 21st century skills practice.

The second and third research questions are primarily targeting the latter half of the input/output model of the STEM learning environment, which includes the black box and the outputs that come out of it. The black box is now populated with the ENA models for each case to better inform how cooccurrences of these two facets of the STEM activities can be associated with the eventual learning outcomes categorized according to their respective lists of epistemics. The two outputs (STEM subject knowledge and 21st century skills) are examined based on how epistemics within each output cooccur. For STEM Subject Knowledge, the epistemics are: 1) science, 2) technology, 3) engineering, and 4) mathematics. For 21st Century Skills Development, the epistemics are the 4C's: 1) communication, 2) collaboration, 3) creativity, and 4) critical thinking (see Figure 44).

The second and third questions focus on the network models as explanatory vehicles for understanding learning according to the perspective of Quantitative Ethnography (QE). In QE, learning is conceptualized as a process of producing more complex connections of meaning between knowledge and skills and the use of ENA allows for mapping this process.

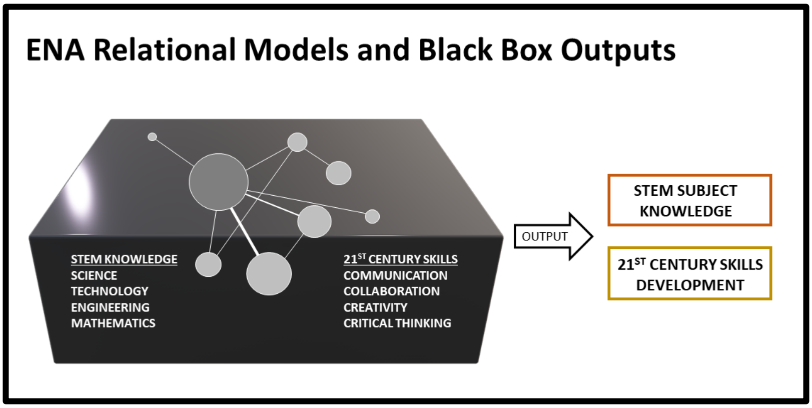

Figure 44: ENA Relational Models and Outputs

6.10 Practical Implication of the Findings

The aim of this research project in anatomizing the three STEM activity cases is to provide some insight into claims about STEM learning with respect to the acquisition or display of subject knowledge and 21st century skills such as communication, collaboration, creativity, and critical thinking. Furthermore, the cases examined here presented an opportunity to explore how hands-on making and the use of engineering students as mentors may contribute to learning as well. Also, despite the use of specific cases and the inherent limits to generalization afforded to case design methodology, the different contexts and levels of expertise exhibited by the participants allows for at least three different contexts to be evaluated. Not only do the cases present an opportunity to discuss STEM activities within non-formal settings, they also provide an opportunity to examine STEM learning activities within tertiary engineering education, and the application of STEM activities within the classroom. Lastly, the use of epistemic network analysis was evaluated for its applicability to the methods and aims of this research and how the tools associated with ENA may provide more practical educational implications for designing and delivering STEM activities in the various contexts of the three non-formal STEM activity cases.

The STEM activities examined here provide evidence for the value of using STEM activities within all levels of education. What is needed is an understanding of what learning outcomes are sought in order to ensure that the use of STEM activities aligns with the goals set out within the student curriculum or within the practical training of engineering students. Furthermore, the non-formal nature of these cases also provides evidence for the need for more investigation into how concepts that are traditionally abhorrent within learning settings, such as cheating, can actually present opportunities to refine 21st century skills.

The greatest challenge for applying the strategies used in the design and delivery of the cases examined here is the need to coordinate between higher education and compulsory education institutions in order to provide engineering students to serve as mentors, and to provide engineering students access to more hackathon scenarios that can be expanded upon in the manner that the three iterations of the cases did so here. The trends in engineering education to include industry stakeholders in preparing students for the practicalities of the 21st century workplace can be applied to consider other means of cooperation in generating STEM learning activities similar to what was provided by the non-profit.

Another practical implication to the findings of this study is associated with the methodological practice that needed to be refined when coding for epistemics in a data source that introduced challenges from the realities of F2F collaborative activities. There was a noted challenge in determining how ENA could be applied to communications that was incomplete, broken, or that applied other nonverbal aids such as object-medicated communication or gestures. This methodological finding can be applied to improving discussions within the QE community about the implications for comparing ENA within online and F2F collaborative settings.

6.11 Opportunities for Future Research

The entire volume of audiovisual data collected within the scope of this study could not be utilized within the time constraints of a doctoral thesis project. This reality alone presents opportunities to expand on the findings of this limited investigation by allowing for the inclusion of more groups from at least the SDP teacher workshop case to expand on the epistemic frame of the case or to create another comparative factor within the case. When expanding the cases, it is also possible to uncover even more learning nuances that can be unique to each participant, or to how each participant is situated within their group, or to how each group as a whole can differ from one another.

Furthermore, there is also the possibility to explore the qualitative analysis in greater detail using more structured methodologies from traditions within social semiotics, conversation analysis, discourse analysis, or even methods from within the learning analytics community such as inquiry-based learning or machine learning. The importance of closing the analytical loop that is communicated within the QE community points to a possible expansion to this study that can move away from a rigid positivist perspective and allow for conclusions to be derived from understanding these cases from a constructivist point of view that can highlight details in the data that have been overlooked or regretfully set aside during this initial investigation.

Furthermore, the many specific findings that may only be relevant to these cases can be tested and applied with the application of a design-based research approach that can make use of the ability of ENA to provide information conducive to cumulative assessment of learning in a STEM activity context. This study presents an opportunity to consider how to adapt the STEM cases investigated here for an online environment, or how to pursue adopting STEM activities within traditional higher education.

The nature of the audiovisual data allows for many possible reinventions of how to improve on this study and find more meaningful insights about STEM activities and how participants create connections between various epistemics that were not originally considered in the scope of this study. During the initial ENA it became apart that the use of the webtool allows for adapting and manipulating the coding of the source data, and even the data transcriptions, to explore other epistemic codes or other temporal aspects of the activities by reinterpreting data segmentation of how the activities were structured.

Over the course of this study, it was possible to consider new perspectives and coding schemes that could be applied to the existing data in order to delve even further into STEM learning as presented by the discussions and actions of the participants in this study. The ability for additional ENA to be conducted is a promising direction to not only apply more complex methods of ENA, but to also consider how various analytical decisions within the ENA webtool can impact on how the networks are generated and interpreted.

7. Conclusion

This research project investigated the processes and interactions taking place over the course of three non-formal STEM activity cases. These processes and interactions combine to create one possible interpretation of the conditions for learning that are present within the learning environments of the STEM activities investigated. These learning conditions illuminate the black box of STEM learning located between the pedagogical inputs into the activity design, and the learning outputs. Shedding light on these processes and interactions offer insights for improving STEM subject knowledge and 21st century skills practice within these non-formal STEM activities. By using relational models that map the cooccurrences of STEM and 21st century skills epistemics, this research showcased how the knowledge/cultural communities generated by the activity participants can provide evidence for the laudable claims about STEM activity effectiveness found in educational literature, while also presenting cautionary insights into the complexity underlying STEM pedagogies.

The main findings reveal that learning theories alone lack the explanatory power to attribute the design of a STEM activity to its learning outputs. When processes and interactions are analyzed to show the complex connections made by the STEM activity participants between STEM and 21st century skills epistemics, a deeper understanding into these learning theories is derived. For example, rather than relying on theoretical foundations to explain or justify hands-on learning as being effective for STEM activities, this research narrowed down this vague idea to isolate the act of tinkering. The specific act of tinkering displayed how participants were making connections between STEM knowledge constructs and the practice of 21st century skills such as critical thinking and creativity, which supported the general claim for hands-on learning but with more applicable detail to make for relevant contributions to the future design of STEM activities.

Following the investigation into the relational models for STEM subject knowledge and 21st century skills, the Quantitative Ethnographic (QE) method required attributing the evidence taken from the epistemic network analysis (ENA) to the source data (e.g., transcriptions and video clips). This process is termed *closing the analytical loop* and provides thicker descriptions for how the network models and the knowledge communities they represent are related to STEM learning inputs and outputs. In general, the findings of this investigation identified the conditions for learning within the black box of STEM learning environments in terms of how processes and interactions can be interpreted by a combined ENA and qualitative reflection of the source data (see Figure 45).

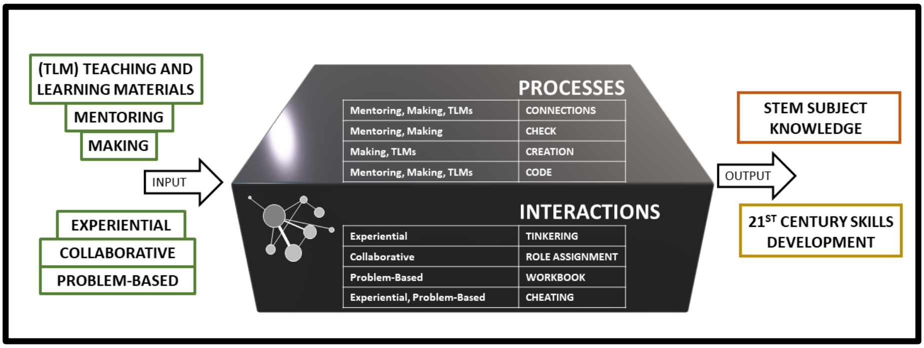

Figure 45: The Complex Learning Environment of STEM Activities

Science, Technology, Engineering, and Mathematics (STEM) learning activities, as highlighted by the cases examined in this research project, are a promising approach to the various pedagogical goals of STEM education with respect to both modern soft skills and subject knowledge development. The three cases, and the individual subcases within them, provide an opportunity to investigate beyond general aspects of STEM learning such as problem-based learning, experiential learning, and collaborative learning.

The cases featured additional characteristics, such as the use of mentorship and maker kit teaching and learning materials, that could also be evaluated in terms of their potential contribution to learning. Finally, the use of epistemic network analysis allowed for a closer examination of various learning opportunities related to STEM pedagogies. For example, finding that the activity of tinkering can be singled out as a specific and tangible aspect of experiential learning helps to provide a more compelling explanation for why STEM activities can produce improved learning outcomes.

However, these findings are still limited to the cases examined and would require more contextual expansion to better understand the learning potential of these activities. This introduces a need for a deeper discussion about the generalizability of the findings of this study overall, and how future work into the topic of STEM activity learning can increase the understanding of what opportunities for learning subject knowledge and the practice of 21st century skills are present within these activities.

7.1 Generalizability

With the ability to identify more concrete explanations for the pedagogical effectiveness of STEM activities, it is possible to address the issue of how the results of this study can be applied to understanding or evaluating other cases of STEM learning. This introduces the concept of generalizability within social science research that deviates from the restrictive dualism founded in the philosophical and terminological juxtaposition between the positivist and interpretative research paradigms.

When considering the implications of *closing the analytical loop* as an integral part of QE methodology, there is a clear movement beyond mere probabilistic or statistical generalization. The mixed-methods approach of QE, combined with using ENA as the foundation from which to qualitatively investigate numerical network parameters, demands a more neutral conception of generalizability. For example, a definition put forward by Carminati (2018) focuses on generalizability as a process of formulating broad statements about specific cases that allow for observations about these cases to underpin inferences about what cannot be directly observed in other cases so long as there is a reasonable transfer of contextual circumstances, data types, and procedural analysis (Carminati, 2018; Hallberg, 2013).

With this definition of generalizability, the findings from this study can be valuable for understanding other STEM learning environments. Specifically, the findings related to the processes and interactions taking place within the black box of the STEM learning environment can be valuable if there is consideration for the related inputs and outputs that are associated to the black box. The implication being that this application of the findings cannot be blind to the complexity in establishing a reasonable transfer when the context and the participants of an activity have roles in shaping the learning environments and outcomes.

7.1.1 Generalizability of Inputs into the Black Box

This neutral concept of generalizability allows for the findings from this small research project to be informative when seeking to understand the conditions for learning that may or may not be present in similar STEM activity contexts. For example, this study pointed to the unique epistemic networks of the mentors within each case, which may provide some understanding of their role in introducing technical knowledge and skillsets into the overall STEM activity's community of practice. When investigating similar STEM cases, it is possible to use this inference about the role of the mentor to evaluate or understand learning within other STEM cases that use mentoring strategies. Also, uncovering the value of "cheating" and attempting to reconsider this concept within STEM activities as opportunities for critical thinking and creativity to manifest, may provide another facet to understanding how to encourage these two

21st century skills to be applied within other learning activities that allow for open-ended answers and problem solving to explore a particular educational topic or subject theme. Lastly, the extraction of tinkering as a valuable facet to experiential learning and hands-on learning, can also be applied within other hands-on contexts to determine if this playful and curious act can be better applied as an explanatory factor for why STEM activities may produce positive learning outcomes.

The conceptualization of STEM learning opportunities as specific processes and interactions taking place within the black box of a STEM activity does not have to be rigidly applied to other investigations into STEM learning. Rather, the focus on uncovering and understanding learning from this perspective is the lesson to be gleaned from this particular research project. A rigid and methodical application of any model generated from only a select few examples of non-formal STEM activities can be fraught with methodological and analytical problems. However, this research can contribute by providing some more distinct features to STEM learning that can be tested or investigated to see if they are present or influential in STEM learning in other contexts.

The findings from this research do not profess to explain STEM learning in general, but do provide explanations for how STEM learning can be more richly understood in contexts that mirror similar learning environments. The analysis of the cases revealed that any application of uncritical generalizability loses the complex facets to any learning context that is shaped by the participants that engage with it. For this reason, although generalizable studies can apply to more rigid schooling environments, this approach can fail to account for the full complexity of STEM learning environments that enable more freedom from traditional educational cultures of teaching and learning.

7.1.2 Generalizability of Outputs from the Black Box

When generalizability is considered from the vantage point of complexity within the processes and interactions that shape STEM activities that are similar in design as the ones presented in this research project, it becomes possible to apply findings from even these small cases to help investigate, but not explain, outputs from other cases of STEM learning. However, generalizing to similar contexts can be difficult when considering the importance placed on the individual participants as shaping the learning processes and outcomes.

The three cases investigated in this research project feature various iterations within essentially the same activity, but with adjustments made to align with the skills and competencies of the participants. The participants in these cases can be broadly grouped as engineering students and Swedish school teachers. The epistemic networks generated by each of the cases highlight connections made between STEM subject knowledge and 21st century skills by both of these groups of participants, whom arguably possess varied levels of expertise. The skillsets and knowledge of the participants present a dilemma in attempting to reproduce the context of these studies and also present a challenge for studies that attempt to measure STEM activity learning outcomes in general ways.

For example, to expand upon studies that find quantifiably improved learning outcomes from STEM education participation, another stage of qualitative analysis of the specific data that contributed to these measures could illuminate details within the STEM learning framework and provide direct evidence for their contribution to learning. (e.g., improved test results for STEM participants). Research findings into STEM learning that focus on the measurement of learning outcomes lose information of what elements within the STEM activity itself can be correlated to what is learned by the students.

Despite the challenges to attributing STEM learning outputs to the processes and interactions of specific learners that may or may not present similarities to other contexts, there is still value to the findings of this study in light of the unique participants in the cases and how they cover both the expert and more untrained leaners of STEM.

7.2 Quantitative 'STEMography'

The application of quantitative ethnographic methods, and specifically the use of epistemic network analysis (ENA), for uncovering and investigating the processes and interactions taking place between participants of a STEM activity, allowed for an understanding of STEM learning that was not possible using more conventional educational research methods. Understandably, not all investigations into STEM learning, and specifically STEM activities, require the use of Quantitative Ethnography (QE) and related methods such as ENA. However, the suitability of this approach for uncovering the veiled process and interactions that can establish more concrete evidence for how inputs and outputs of a STEM learning environment are interrelated provides valid justification for future research into STEM learning to pursue QE approaches.

The reasoning for the use of QE and ENA is further supported by contemporary trends in data collection and processing. More data is becoming increasingly available from within educational settings as modern learning environments embrace digital and technological instruments for teaching and learning. This pushes the applicability of learning analytics for addressing the increasing amounts and complexity of learning data and information generated from learning settings that are both online or in-person. The context of STEM activities (especially those situated within non-formal learning contexts—i.e., outside of school classrooms) are well suited to more novel research methods that can attempt to capture the sort of rich and complex data that is required for this sort of data-driven educational research.

The exploration of STEM activities using audio-visual data and quantitative ethnographic methodology may also help to stretch the limits of ENA in a direction that can increasingly refine the method to represent educational phenomena similar to what is found within STEM activities situated within both online and in-person contexts—dynamic, temporal, and complex group interactions that embrace learning strategies that deviate from traditional classroom models, and which often involve multimodal communicative enactments or silences that nonetheless are loaded with implications.

Although it is possible to showcase how ENA can be used and interpreted for understanding communicative activity and creative processes in some STEM activities, this sample does not adequately highlight the overall goal of using ENA to create a larger STEM-based epistemic frame of learning. Below are some ways in which this study may contribute to the body of knowledge about STEM learning and education by outlining possible implications for three contexts for STEM education that can be investigated using QE approaches. These three contexts reflect the unique aspects of each case and how they relate to STEM learning activities within: 1) the secondary level of compulsory schooling (in Sweden); 2) higher education associated with the STEM pipeline; and 3) non-formal learning activities outside of the formal education system. Furthermore, the cases also align with the growing popularity of consumer STEM "kits" or "boxes" as pedagogical materials.

This research project accomplished its specific goal of understanding what takes place within the black box of the three STEM activities investigated. This goal was accomplished using ENA and QE methods. However, this research project is merely one step in the direction of understanding STEM learning in a manner that can be more confidently grounded on evidence generated by STEM activity participants themselves. In the spirit of the ethnographic foundations of QE methods and ENA, a thicker description of STEM learning requires that more steps be taken toward refining our understanding of the learning processes underpinning effective STEM education. This research should therefore be conceptualized as just one phase in a multi-phase iterative study into generating an understanding of learning within STEM learning activities.

The next step, whether taken by this researcher, other members of the QE research community, or by you the reader, is waiting to be taken.

Svensk Sammanfattning

Detta forskningsprojekt är inriktat på att förstå vad som sker inom specifika lärandeaktiviteter inom det integrerade ämnesområdet STEM, Science, Technology, Engineering och Mathematics (naturvetenskap, teknologi, ingenjörsvetenskap och matematik). Inom STEM-utbildning behandlas dessa fyra ämnen som sammanslagna, snarare än som separata discipliner. Detta integrerade tillvägagångssätt – att förena dessa fyra ämnen till ett område – kräver att kunskap inom alla fyra områden både lärs och används vid problemlösning eller vid utförandet av olika uppgifter. Dessa problem eller uppgifter speglar de frågor och utmaningar som elever kan möta utanför klassrummet, där det inte finns någon tydlig uppdelning mellan de fyra ämnena. Undervisning och lärande inom STEM utgår från uppfattningen att verkliga problem kräver integrerad kunskap från samtliga ämnesområden.

I stället för att utgå från ett systemteoretiskt synsätt – där man identifierar ingångsvärden i en STEM-lärandekontext och sedan utvärderar resultat för att bedöma aktivitetens effektivitet (Bhaskar & Lajwanti, 2019) – fokuserar denna forskning på de processer som sker inom aktiviteten. Dessa sammanlänkade processer kan ge förståelse för hur lärande sker genom att identifiera möjligheter att tillägna sig ämneskunskaper inom STEM och att öva på färdigheter som anses viktiga för framtiden, sk. 21st century skills.

STEM-utbildning kan göras på många skilda sätt, varav en är STEM-aktiviteter. Dessa förekommer både inom och utanför skolundervisningen och är utformade för att främja praktiskt, samarbetsinriktat och problembaserat lärande. Syftet är att stödja kunskapsutveckling och främja användningen av färdigheter relevanta för arbetslivet. STEM-aktiviteter bedöms ofta utifrån hur väl de uppfyller tre mål: att stimulera intresse för STEM-yrken, förbättra ämneskunskaper i alla fyra områden, samt utveckla sociala och arbetsrelaterade färdigheter (Devrani et al., 2024).

Detta forskningsprojekt fokuserar dock inte på att mäta effektivitet. I stället undersöks de olika typer av interaktionsprocesser och samtal som äger rum under aktiviteten. Syftet är att förstå hur olika komponenter samverkar och hur dessa relationer bidrar till vår förståelse av STEM-lärande och resultat av STEM-aktiviteter.

Fokus ligger särskilt på fyra specifika färdigheter för det 21:a århundradet: samarbete, kommunikation, kreativitet och kritiskt tänkande (collaboration, communication, creativity, and critical thinking; the 4C’s). Dessa färdigheter nämns ofta i litteraturen om STEM-lärande, men det är ovanligt att alla fyra undersöks samtidigt och i relation till både varandra och till ämneskunskaper inom de fyra STEM-ämnena. Studien strävar efter att identifiera mönster i hur dessa kunskaper och färdigheter används och utvecklas under en STEM-aktivitet.

Även om tidigare forskning visar att STEM-utbildning kan leda till positiva läranderesultat, saknas ofta detaljerade beskrivningar av själva lärandeprocessen. Denna studie använder en metod som tar hänsyn till samtliga variabler i STEM-lärande som ett sammanhängande nätverk, i stället för att betrakta dem isolerat. Detta gör det möjligt att få en mer heltäckande förståelse för hur integrerad ämneskunskap och 4C-färdigheter samverkar.

Projektet bygger på videoinspelningar av handlingar och samtal i tre grupper som deltog i tre olika STEM-aktiviteter. En rapport från 2022 beskriver hur Sverige genomfört initiativ för att förbättra undervisningen i matematik och naturvetenskap genom STEM-aktiviteter, både inom och utanför den formella skolan (Hartell & Buckley, 2022). De fall som undersöks här är hämtade från den icke-formella utbildningssektorn, där aktiviteterna genomförts i samverkan med formella utbildningsinstitutioner. Urvalet gjordes utifrån tillgänglighet, då det finns få praktiskt orienterade STEM-aktiviteter i icke-formella miljöer.

Den första och tredje gruppen hade fem deltagare vardera, medan den andra bestod av två. I varje aktivitet samarbetade deltagarna för att designa, bygga och programmera en elektrisk leksaksbil. Videomaterialet analyserades för att identifiera både verbala och icke-verbala uttryck för användning av ämneskunskaper och utövande av 4C-färdigheter.

Forskningsmetoden som användes var kvantitativ etnografi (QE), som syftar till att förstå lärande genom att analysera hur kopplingar uppstår mellan olika epistemologiska begrepp inom en lärandekultur (Shaffer, 2017). Metoden kombinerar epistemisk nätverksanalys (ENA) och kvalitativ dokumentanalys (QDA). Ett webbaserat analysverktyg användes för att generera nätverksmodeller som visar kopplingar mellan ämneskunskaperna och 21st century skills. Dessa modeller jämfördes mellan grupper och mellan enskilda deltagare för att identifiera signifikanta mönster. Därefter kopplades nätverksmönstren tillbaka till ursprungsdata – videomaterial och transkriptioner – för att bättre förstå hur lärandeprocesser tar form i en STEM-aktivitet.

Resultaten sammanfattas endast kortfattat här. Flera brister i STEM-effektivitet identifierades, vilket överensstämmer med tidigare forskning. Exempelvis framkom att ämnena inte alltid integrerades balanserat, och att matematik ofta var underrepresenterat. Grupparbete kunde också utgöra ett hinder för individuell tillgång till alla fyra ämnen och 4C-färdigheter. Deltagare som arbetade med kodning uppvisade andra kopplingar mellan färdigheter och kunskaper än de som fokuserade på exempelvis elektronik eller design.

Samtidigt pekade studien på möjliga förbättringar av STEM-aktiviteters lärandemål. I samtliga fall identifierades starka kopplingar mellan regelbrott och kreativitet samt kritiskt tänkande. Användning av "fusk" i STEM-aktiviteter kan därför ha en pedagogisk funktion. Det framkom även att så kallad "tinkering" – att experimentera med komponenter och föremål – starkt hänger ihop med kritiskt tänkande. Detta antyder att STEM-aktiviteter bör uppmuntra till lekfull nyfikenhet, snarare än att enbart fokusera på slutförande. Slutligen visade studien att undervisningens utformning spelar en avgörande roll, då närvaron av en mentor med expertis inom området inte bara tillförde ämneskunskap till gruppen, utan också påverkade hur deltagarna använde 4C-färdigheterna.

För en djupare redogörelse hänvisas till den formella avhandlingstexten. Förhoppningen är att detta arbete bidrar till fortsatt dialog och utveckling av STEM-utbildning för elever i alla åldrar.

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Appendix

Appendix: Sample of Construct Coding from Transcript

Utterance (lines 568 - 639)	**STEM. sci**	**STEM. tech**	**STEM. eng**	**STEM. math**	**TCS.co mm**	**TCS.cr eate**	**TCS.cri t-think**	**TCS.co llab**
Task nine					Task nine			Task nine
yes					yes			yes
microbit...task nine...task...nine...task nine (typing on laptop)...theeee...microbit...there we go		micro-bit						
just let me...i think we need to disconnect the...(fiddles with the device on the table)		dis-con-nent					I think	we
ok...why?					why			ok
oh, (stops fiddling with the device) can we...ok let me try the (takes microUSB and attaches it to the device on the table)		At-taches it to device			Oh… ok		Let me try	Can we
fair enough...here is the mirco...USB (hands it to S2 who in turn plugs it into the intake device on the table while S1 plugs the other end into laptop)	Plugs it in…other end into laptop				Fair enough			(hands it to)
alrighty...ok this thing does not make any sense (indicates something to non-profit that has just walked over to the table)...this should be a range			Should be a range	range	Ok…		Does not make any sense	
yeah, (scratches head) i know, there might...there are different thresholds that can work		thresh olds	Thresh olds that can work	Differ-ent thresh olds			There might be…	
i know but it doesn't make...this should be a range (pointing to something in the workbook)				range	I know but…		It doesn't make sense	point-ing
(all three pausing to look at each other) yeah but for your code you need one number, right?		code			Yeah but		You need one num-ber Right?	

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ok, fair enough. that's the number you put...					Ok,		That's the number you put...	Fair enough
yeah...a number that works, not always the same number and different teams will come up with different numbers	Teams will come up with different numbers			Different numbers	Yeah...			
cause the sensors...		sensors	Cause the sensors				Cause ...	
yeah, but a number that works is good enough			Number that works is good enough	Number that works			Yeah, but	
did you upload it?		upload			?			Did you
yeah, let me see copy right now		copy			yeah			
doesn't look like so (all pause to watch the device that is held by S2 who is fiddling with it)								Doesn't look like
here you go...(closes the laptop)								Here you go
two, three, twenty three...23 seems to be ambient (looking at the device in hand)	ambient	Device in hand	Device in hand	Two, three, twenty, twenty three	1			Seems to be
uhmm (agreement)					uhmm			
now let's try...(picks up mobile phone with light and shines on the device in hand)	Now lets try (shines)	Light on device						Let's try
what is it? one four...(looking at the device)				What is it?	?			What is it
I am not sure that looks right...	Looks right	Looks right			1		Not sure that looks right	

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is there something wrong with the code? (puts the device down on the table)		code	Wrong with the code		?		Is there some-thing wrong	Is there…
(opens laptop again) ummhmmm, let me...							Let me…	
did you use the right pin, pin zero? (picks up the device)		Pin, pin zero	P0		?		Did you use the right pin	
i think I know what's wrong you have plugged in the...(points to something on the device while S1 and S2 lean over and closer to look at what non-profit is indicating)		Plugge d in			points		I think I know	1
ahhh (inhales sharply and nods)					nods			
wrong pin		Wrong pin	Wrong pin					
(laughs) ahhh booo...								
yeah ok					ok			
that was not pin two		Pin two	Pin two		That was not pin two			
so we need to buy another cable now		cable	Need… an-other cable	buy			Se we need	
ah, ok								ok
oh nooo...(joking sarcasm) i will bring one for you					joking			For you
(to S1) get a type A or...?		Type A	1		1			Or…
task nine, one cable more (types on laptop)				One more	typing			
wire type A did you say					Wire type A			You say
yup, yeah the...female cable		Fe-male cable	Fe-male cable		yup			
it doesn't matter what wire it is		What wire	Doesn’ t mat-ter what wire		It doesn’ t mat-ter			
yeah but it is easier to connect		Easier to con-nect	con-nect		Yeah but		easier	Yeah but

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yeah (laughs)...I mean for the calculations (looking over the S1 and laptop) not for the project			Not for the project	calculations	yeah			
ok					ok			
so now the ambient light (has been connecting the wire) we are seeing...one nine three	Ambient light	We are seeing		One nine three	We are seeing…one nine three			We are seeing
ok					ok			ok
ok around one nine five (write in the workbook)				One nine five	ok			Ok around
(places mobile phone light over the device) and now...we are looking at three zero nine, is that right? can you check again	Check again	Look at…is that right		Three zero nine	And now		Is that right?	We are looking at
six nine two...				six nine two...				
six nine two					six nine two			
six one...(shrugs) six ten				Six ten	shrug			Six ten
ok (writes in the workbook)					ok			ok
so we can take something maybe in between...what was it four hundred or something?			Take something in between	Something in between …Four hunred	So we can take		Take something maybe	We can
(nods) ummmhmm, yeah					yeah			
great, that will be...because now its not going...yeah it's in the lower two hundreds so we should be safe with four hundred		Not going	Now its not going	Lower two hundreds …Safe with four hundred	great		Should be safe	
and to make it easier to...we can do it later but maybe easier to read if we can actually divide by 100 so we only show one single digit				Divide by 100…only show one single digit		Make it easier	Easier to read	We could do it later but

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hey, you know what...I think what we should do is check what the six hundred is and check it with the voltage	Check with the voltage	voltage	Check what… check it with	What is the six hundred	hey	Check what	You know what…	We should
(nods) hmmm					nods			
there is a question here later on (points in the workbook of S2)					points			
ahh,					ahh			
oh perfect					perfect			
so if you see what you measured from task six, the numbers don't really match right?...with what you see here on the screen (points to device)		See here on the screen		Measured… numbers don't really match	So if you see		Don't really match right?	If you see what you measured
yeah that's true (looks up at non-profit)					Looks up			
do you know why?	Know why				Do you know		why	
ahhh...why?...well...(points to multimeter)...the...the way this (device) reads and the way this reads is different...		The way this reads	This reads	This read is different	Ahh… why?		Well…	
so the microbit is digital...your light sensor is analog (both S1 and S2 nod)...and on the pins of the microbit that work as output...as input, sorry, there is an analog to digital converter (S1 nodding throughout). so it takes whatever analog value the light sensor gives and converts it to something between zero and 1023. so it's like (slight flapping hands motion) a ratio of one to your multimeter reading (S2 nodding and looking over the workbook)	Digital…analog	Light sensor, microbit, mulitmeter	An analog to digital converter, ratio	Value …converts it…between zero and 1023	nodding			
but it makes sense thought, because six hundred is almost like two-thirds of 1000 and also we measure two out of three volts...		Measure volts.		2/3 of			It makes sense	We measure
exactly, yeah it's different number but its the same concept	Same concept		concept	Different	exactly			

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				num-bers but				
ok (nods). we need to explain that as a teaching moment (laughs)					nods		Teach-ing mo-ment	We need to ex-plain
exactly! yeah, that was a nice ques-tion (to S2)					yeah			Nice ques-tion
yeah, perfect					per-fect			
so should we move on to number ten					Move on			Should we

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