Learner-generated drawings in physics education

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12.08.2013
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Contents

Abstract

Different kinds of visual representations, such as graphs and drawings are important in education but especially in science education. Little attention is paid especially to drawings. Students are required to examine drawings and assimilate the information conveyed by them but not much attention is paid to the students' own drawings. Arguments can be made for the importance of learner-generated drawings in science education.

The subject of this thesis is the use of learner-generated drawings in physics education. A study was conducted to study the use of learner-generated drawings as a tool for meaning-making. The study involved 36 upper secondary school students who were given a drawing assignment about the kinetic theory of gases. The students also had to solve few assignments by drawing the answer. The students drew in small groups and the drawing process and the students' talk were recorded using iPads. The quality of the students' talk was analysed. The effect of guidance in the drawing process was also studied. Half of the groups received guidance by comparing their own drawing to another drawing about the same subject.

The students used drawings and talk as psychological tools that helped them process their internal models and to visualize and verbalize them. Many of the drawings produced resembled traditional text books drawings. It seems that the most of the students had learned the conventions of drawing the kinetic theory of gases. Statistical methods show that students who received guidance drew more accurately than the control group.

The students' talk was generally cumulative and uncritical. Seldom did the students open up the conversation and look for alternative solutions. iPads performed well as research equipment. They offer some benefits over traditional research equipment. There is a need for specially coded applications for education research for tablet computers. At the end of this thesis ideas for future research are presented.

Tiivistelmä

Erilaiset visuaaliset representaatiot, kuten kuvaajat ja piirrokset, ovat tärkeitä opetuksessa. Erityisen tärkeitä ne ovat luonnontieteiden opetuksessa. Piirroksiin ei juurikaan kiinnitetä huomiota. Opiskelijoiden tulee tarkastella piirroksia ja sisäistää niiden sisältämä tieto, mutta erittäin harvoin opiskelijat itse pääsevät tuottamaan piirroksia. Opiskelijoiden tuottamien piirrosten tärkeys luonnontieteiden oppimisessa on viime aikoina nostettu esiin.

Tämän tutkielman aiheena on opiskelijoiden tekemien piirrosten käyttö fysiikan opetuksessa. Yhtenä tutkimustavoitteena oli tutkia, kuinka oppilaat käyttävät piirroksiaan merkitysten luomiseen. Tutkielmaan liittyvään tutkimukseen osallistui 36 lukiolaista. Heille annettiin tehtäväksi piirtää heidän käsityksensä kineettisestä kaasuteoriasta. Opiskelijoiden tuli myös vastata muutamaan tehtävään piirtämällä heidän vastauksensa. Opiskelijat piirsivät pienissä ryhmissä ja piirrosprosessi sekä opiskelijoiden puhe tallennettiin käyttämällä iPad-laitteita. Tuen merkitys piirtämiseen oli myös tutkimuskohteena. Puolet ryhmistä sai tukea piirtämiseen siten, että heille näytettiin valmis piirros samasta aiheesta.

Opiskelijat käyttivät puhetta ja piirroksia psykologisina työkaluina, jotka auttoivat heitä prosessoimaan sisäisiä mallejaan ja kuvaamaan niitä sekä visuaalisesti että verbaalisesti. Monet piirroksista muistuttivat perinteistä oppikirjakuvitusta. Opiskelijat olivat oppineet kineettiseen kaasuteoriaan liittyvät piirroskonventiot. Tilastolliset testit osoittavat että opiskelijat, jotka saivat tukea piirrosprosessiin, piirsivät tarkemmin kuin he, jotka eivät saaneet tukea.

Opiskelijoiden puhe oli yleisesti kumuloituvaa ja epäkriittistä. Opiskelijat vain harvoin avasivat keskustelua ja etsivät vaihtoehtoisia ratkaisuja. iPadit toimivat hyvin tutkimusvälineinä. Ne tuovat joitain etuja verrattuna perinteisiin tutkimusvälineisiin. On kuitenkin tarve kehittää erityisesti opetuksen tutkimiseen tarkoitettuja sovelluksia. Tutkielman lopuksi esitellään jatkotutkimusideoita.

Acknowledgements

I'm thankful for the Department of Physics for hiring me for two consecutive summers to work on my Candidate's and Master's Theses. This financial support has enabled me to work my theses full time and to focus my full attention to research.

I would like to thank everyone in the science and mathematics section of the Department of Teacher Education. They have been very helpful and given me ideas on how to proceed. Doctor Jaume Ametller gave me a fresh perspective to the study. A special thank you goes to Doctor of Philosophy Pasi Nieminen for our daily talks and to Docent Antti Savinanen for his ideas. I would also like to thank the teacher who let me use his/hers lessons for the study.

Professor Jouni Viiri has shown very much attention to my thesis and his enthusiasm has been an inspiration to me. I'm grateful that he listened to my idea for this thesis and agreed to guide me. He has given me countless references and new ideas for this thesis when I have been clueless about what to do next.

Lastly I would like to thank my beloved Auli for her support and love. She has given me energy to continue. She was there for me when the writing seemed too hard to continue. It's fate that our interests are so similar.

1. Representations and models in physics education

1.1 Defining the concepts

Science can be described as a field of study in which various natural phenomena are investigated. A *model* is defined in science as a *representation* of these phenomena that is initially produced for a specific purpose (Gilbert, Boulter, & Elmer, 2000). A model is usually a simplification of the phenomenon in question that is produced so one can develop an explanation for it. For example, in the kinetic theory of gases the particles of the gas are assumed to be point-like while in reality they have a small volume. Some features of the studied phenomenon can also be left out of the model. For example the Bohr's atom model leaves out the interactions the modelled atom has with other atoms in the system. These interactions are not important when the area of study is the basic structure of the atom. Models and modelling can be seen as a very important part of doing science because they can be used to explain what is seen and to predict what might be seen (Gilbert, 2005b). In order to that to succeed, the model must represent at least a part of the studied phenomenon (Frigg, 2006). In other words, a model must be representational.

Models can represent something concrete, for example a pulley or a wheel or they can represent something abstract, like a force or energy. Models can mix concrete objects and abstract concepts. An example of this is modelling friction on an incline. Friction is an abstract concept, but the object that is used to study friction is a concrete object. Events like vaporization of water can also be modelled.

Models can be classified to different ontological groups. One of these classifications (Gilbert et al., 2000) is presented below (Table 1):

Table 1: An ontological classification of models (Gilbert et al., 2000)**.**

Name of the model type	Description of the model type
Mental model	A personal cognitive representation of a phenomenon.
Expressed model	A model that is used by an individual to interact with others and to express mental models to them. Expressing a mental model has an effect on it.
Consensus model	An expressed model that seems valuable and useful to a group of people. When an expressed model formulated by a scientist goes through experimental testing and is deemed worthy of further study it becomes a *scientific model*.
Historical model	A consensus model, which has been superseded by later models (e.g. atom models throughout history).
Curricular model	A scientific model, which has been deemed worthy to be included in a formal curriculum.
Teaching models	A model that is used by teachers to help them develop understanding in the class.
Hybrid model	A model that is formed by combining characteristics from many different scientific, historical or curricular models.
A model of pedagogy	A model that is used by teachers for classroom activity. Different teachers have different perspectives on teaching and learning.

Because models and modelling play a big role in science, it therefore follows that they should also be a part of science education (Laugksch, 2000). When students learn how to use different models for different problems, they learn about what it's like to be a scientist. All students will need some level of "scientific literacy" in their later life. This study reported in this thesis aims to look into the use of expressed models by upper secondary school students.

Three distinct reasons can be found for why models and modelling are important in science education (Gilbert et al., 2000).

1. The formation of mental models and the presentation of mental models are essential to the development of understanding of any phenomenon.

2. The production and experimental testing of expressed models is a central part of science. Scientists produce models and then share them with each other in order to develop them further and to develop a consensus model.

3. Historical and scientific models are major outcomes of science. When learning science, one must develop an understanding of major historical and scientific models.

Models in science aim to represent a phenomenon. Representation can be defined as a process in which one tries to represent an object or a phenomenon (G. Kress & van Leeuwen, 1996). The person making the representation selects the aspects of the object or the phenomena which are to be represented according to his/hers interests. These interests rise from the cultural, social and psychological history of the person making the representation. The context in which the representation is used also affects the choice of features that are represented.

Models are expressed using different modes of representation. These modes describe the medium in which the expressed model is rendered. A *mode* is defined as an organized, regular, socially specific meaning-making resource (G. R. Kress, Charalampos, & Ogborn, 2001). A *medium* on the other hand is a material substance which is worked on or shaped over time by culture to a mode. For example, the medium of sound has been worked into the mode of music (G. R. Kress et al., 2001). Teachers use different modes in their teaching, usually combining two or more modes e.g. when talking to class and at the same time using their hands to express the subject. Multiple modes are useful to convey information about the phenomenon, for example when using drawing as an expressed model and combining explanatory text with the drawing. Use of these so called mixed modes is called *multimodality* (Waldrip, Prain, & Carolan, 2006). Communication in itself is a multimodal process. Jewitt, Kress, Ogborn and Tsatsarelis describe how people use multimodality in their everyday life:

> "*-- There is now an increasing understanding that occasions of communication always draw on a multiplicity of modes of communication at the same time. When we speak we also make facial expressions, we gesture, stand at a certain distance, and so on, all of which make meaning together. This ensemble of modes we regard as the normal condition of communication and we refer to that as multimodal communication or as multimodality. --*" (Jewitt, Kress, Ogborn, & Tsatsarelis, 2001)

Modes of expression can be classified in different ways. These classifications are called *typologies*. Typologies can be formulated also for different modes of representations and expressed models in science (Boulter & Buckley, 2000). The typology presented includes pure modes of representation and also mixed modes in which different modes are used simultaneously. Modes listed in Boulter's and Buckley's typology don't include etc. music, so it is not a list of all the modes in the world. It is made to represent the most typical modes in science. The following table lists the previously mentioned typology's modes (Table 2).

Table 2: A typology of different modes of representation (Boulter & Buckley, 2000).

Mode of representation	Description of the mode of representation
Concrete	Material models; e.g. a scale model of the Solar System
Verbal	Written or spoken models, descriptions or explanations
Visual	Models that are seen, such as drawings or videos
Mathematical	Models that use formulae or equations a represent a phenomenon
Gestural	Models that are movements of the body: e.g. using hands to describe how the planets orbit each other
Concrete mixed	Concrete models combined with visual, verbal and/or mathematical components
Verbal mixed	Text with visual and/or numerical components; e.g. description of an atom with a related diagram
Visual mixed	Visual models with verbal and/or numerical components; e.g. a diagram of an atom with explanatory labels
Mathematical mixed	Equations and formulae with verbal explanations; e.g. Newton's second law as an equation with explanatory text
Gestural mixed	Acted out representations with verbal explanations

1.2 The connection between representations and models

A phenomenon can be represented using different kinds of representations and models. Models and representations are both based on a particular phenomenon. That phenomenon can be modelled using an expressed model that simplifies the phenomenon so that it is easier to study. This expressed model can be represented using different modes of representations. An example of how these concepts are connected is presented below (Figure 1):

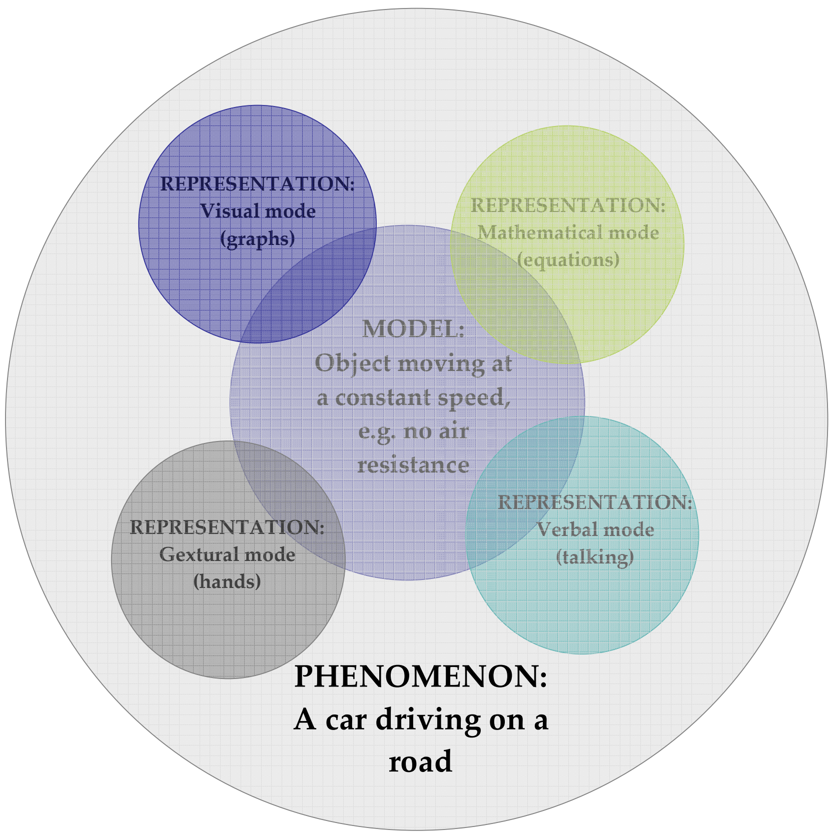


Figure 1: How the concepts of phenomenon, model and representation are connected

Different representations have different functions in learning. Ainsworth names three different functions for the use of multiple representations (Ainsworth, 1999a; Ainsworth, 1999b; Ainsworth, 2006; Ainsworth, 2008):

1) Multiple representations can be used to *complement other representations*. Different representations of the same phenomenon cause different kinds of computational processes. By using different representations to learn about the phenomenon, one is less likely to be limited by the strengths and weaknesses of any single representation.

2) Multiple representations can be used to *support complementary information.* One representation may not contain all the necessary information about the phenomenon to really understand it. The case could also be that attempting to combine all the relevant information to one representation may cause it to become too complicated to understand. In these cases multiple representations can be used to give all the needed information to understand the phenomenon or to solve a particular problem.

3) Multiple representations can be used to *constrain interpretation*. Familiar representations maybe used to support a less familiar representation. The familiar representation can constrain the interpretation of other representations.

Different modes of representations have different *affordances*. The verb "to afford" means: "to make available, give forth, or provide naturally or inevitably" (Merriam-Webster, 2013). In science education affordance is also defined (G. R. Kress et al., 2001) as the answer to a question: *"What constrains and possibilities for making meaning are offered by each mode present for representation in the science classroom, and what use is made of them?"* It can be argued that the word affordance can also be used to describe the constraints and the possibilities of different representations within the same mode. If the visual mode is taken as an example, different pictures or drawings about the same subject can have very different affordances. A drawing made by a student is likely very different than a drawing made by a scientist. A child looking at those two drawings can see them differently than either one of them intended to.

Researchers suggest that the use of multiple representations is very important in science education (Dufresne, Gerace, & Leonard, 1997; Heller & Reif, 1982; Van Heuvelen, 1991). Studies have shown that students learn more deeply with the use of pictures connected with text than just from text alone (R. E. Mayer, 2003). The role of the teacher is to make sure that the students are able to comprehend, use and combine a sufficient amount of representations (Sorvo, 2011).

1.3 Studies about multiple representations in learning science

Multiple studies have shown the importance of multiple representations in learning science and in problem solving. A study (Kozma & Russell, 1997) investigated the differences between experts and novices in chemistry in utilizing multiple representations. The experts were professional chemists and graduate chemistry students and the novices were college students taking a general chemistry course. The results showed that experts were able to use multiple representations better that novices. The participants of the study were provided with a range of representations concerning chemistry and were asked to group them in a meaningful way. The groupings by the experts were more chemically meaningful and larger. The groupings by the novices were smaller and focused more on the same representation types. Experts were also better at transforming information from one representation mode to another, in particular from other representations modes to verbal representation modes.

In another study (Van Heuvelen & Zou, 2000) the impact that a multi-representational college engineering course on work and energy had on the students was studied. During the course work-energy processes were represented in multiple ways, using words, sketches, bar charts and equations. The modes of representation used were the verbal, visual and mathematical mode[1]. The results were compared to a traditional calculus-based course. The students were also asked to evaluate if the multiple representations were useful in learning. Only 7% of the students thought that the multi-representational type of teaching was not useful and 84% of

[1] According to Table 2

the students thought that the strategy used was helpful to learning. When evaluating student performance, about 60% of the students who were taught using the multi-representational strategy gave a right answer to a question related to work and energy on a test at the end of the course. The results were much better than in the traditionally taught control group in which only 20% of the students knew the right answer.

In an Australian study (Hubber, Tytler, & Haslam, 2010) the concept of force was taught to year 7 students from three different Australian classes. Teachers, whose classes participated in the study, were advised to use multiple representations of force and motion and to encourage the students to make their own representations about the concept of force. The teachers were also advised to discuss about the uses for different representations with the students and to allow time for exploring the meaning of representations of force. After teaching the students about force using the new representational method, the teachers were more open to discussion with the students; they paid more attention to representational conventions and used more modes of representations in their explanations. The teachers noted that their students used richer language when talking about force compared to students taught using a more traditional method of teaching. The students also engaged more in class and performed better in their workbooks.

The relationship between students' problem-solving performance and the representational format in which the problem is given has also been studied (Meltzer, 2005). The results indicate that the students gave more correct answers when the question was posed in a verbal representation rather than in a diagrammatic (visual[2]) representation. Recently a Finnish study (Nieminen, Savinainen, & Viiri, 2012) has shown quantitatively that representational consistency is related to the learning of forces. Representational consistency means the ability to identify the same phenomenon even when it's represented using different representations.

[2] According to Table 2

2. Sociocultural view of learning

2.1 Sociocultural theory and the ZPD

In the last 30 years, the research about teaching, learning and cognitive development has revolved around a theoretical perspective usually called "*sociocultural*" but sometimes as "socio-historical" or "cultural-historical" (Mercer, 2004). The main principles of the sociocultural perspective into communication, thinking and learning are that these three processes are related to each other and shaped by culture. People work together to construct understanding and share knowledge. Meaning-making is a dialogic process where language serves as a tool that enables knowledge to be shared and to be evolved (Driver, Asoko, Leach, Scott, & Mortimer, 1994). Sociocultural perspective also highlights the key role of the more experienced learners in helping the less competent learners in a way of scaffolding (Pollard et al., 2008). Peer interaction enables the elaboration of knowledge and hence promotes individual cognitive progress (Van Boxtel, 2004).

Sociocultural theory is based on Russian psychologist's Lev Vygotsky's theory (Vygotsky, 1962; Vygotsky, 1978) which states that learning through meaningful interactions with surroundings and other people are essential to the development of new knowledge. The sociocultural perspective to education is that education is a dialogic process in which the students and the teachers are taking part of. It also highlights the relationship between language and thinking. Vygotsky claims (Vygotsky, 1978) that *intermental* (social) activity will promote *intramental* (individual) intellectual development. This claim has been widely accepted but there isn't much empirical evidence supporting the claim (Mercer, 2004). Lately interest has arisen towards the area of dialogic education. It is a part of the move towards challenging the prevailing school culture which is mostly interested in individual learning outcomes and doesn't give room to discussions and reflection (Lehesvuori, 2013).

Sociocultural theory of learning is also closely connected Vygotsky's famous concept of *zone of proximal development* (ZPD) (Vygotsky, 1978). Vygotsky himself defined ZPD as

> *"…the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers.* –" (Vygotsky, 1978)

ZPD determines the lower and upper bounds in instruction and teaching. According to Vygotsky, instruction is only useful when it is slightly ahead of a learner's development and provides him/her with meaningful but challenging tasks that still are not beyond the learner's capability (Vygotsky, 1978). Vygotsky's definition of ZPD also highlights the need for social interaction to aid in learning.

When a group of people are faced with a problem they must solve together, the members of the group communicate with each other in order to share not just information but also ideas. When working together people do not just interact, they *interthink* (Mercer, 2000). Language is the tool that enables this communication. Vygotsky himself described language as having two main functions (Mercer, 2000). We humans use language as a *communicative tool* to share information and develop the cultures which enable organized human social life to exist and continue. Early in our childhood we begin to use language also as a *psychological* or *cultural tool* for organizing our thoughts and to reason, plan and review our actions. This can be seen e.g. in toddlers when they speak aloud their actions. As Vygotsky puts it:

> *"Children solve practical tasks with the help of their speech, as well as with their eyes and hands."*(Vygotsky, 1978)

Vygotsky also lists other possible psychological tools than language. These include:

> *"…various systems for counting; mnemonic techniques; algebraic symbol systems; works of art; writing; schemes, diagrams, maps, and technical drawings; all sorts of conventional signs, and so on.--"* (Vygotsky, 1997, p.85)

Different kinds on visual representations, such as drawings, could also serve as psychological tools that can help us make sense of our internal models (see chapter 1.1) and to help us process information. This thesis is concerned with how upper secondary school students use drawings and language as tools for meaning-making.

2.2 Sociocultural discourse analysis

Since socio-cultural theory emphasises the role of talk in learning, different methods have been developed in order to study how spoken language is used as a tool for thinking collectively. This area of investigation is called *sociocultural discourse analysis* (Mercer, 2004). Its interests lie in the uses of language in order to engage in a joint intellectual activity. It is concerned with the lexical (from the word *lexicon* meaning *vocabulary*) content of talk and how different parts of talk are connected to each other. The choice of words and patterns in talk can represent ways that knowledge is being constructed together. Different typologies have been developed in order to study students' talk. The typology used in the study reported in this thesis is presented later in chapter 7.2.

In sociocultural discourse analysis the historical and cultural backgrounds of the speakers must be taken in to account. This raises a key problem in the analysis: how can the researcher get an insight about how the speakers construct the contextual background in their talk (Mercer, 2004). Speakers can talk about events they have experienced together or about similar, but different events they have experienced. These shared experiences enable the speakers to use language in a part in their own context which is based on the shared experiences. Similarly the cultural background of the speakers influences the language the speakers use. Researchers can only get information about the contextual background by analysing the speakers' discourse and drawing conclusions based on the common background the researchers and the speakers have. This can influence the analysis of the talk.

2.3 Scaffolding and guidance

The term *scaffolding* in education was first introduced in 1976 (Wood, Bruner, & Ross, 1976). It was used to describe a kind of support that enables a learner to solve problems and complete tasks that were beyond the learner's initial capacity. The concept of scaffolding is connected to Vygotsky's famous concept of ZPD (Vygotsky, 1978) discussed in chapter 2.1. Other terms used to refer instructional support during learning are instructional methods, instructional strategies or teaching strategies and direct instruction (Clark, 2009). The term scaffolding comes from engineering where it refers to an external frame that is used to support a building under construction. The scaffolding is gradually withdrawn as the building gets stronger. Similarly in education the purpose of scaffolding is to make it unnecessary (Pea, 2004). When the learners skills develop, he/she doesn't need the scaffolding anymore. It could even hinder the development of the learner (Lin et al., 2012; Van Merriënboer & Sweller, 2005). An example on scaffolding in everyday life is training wheels on bicycles. When a child is learning how to cycle, he/she needs training wheels to stay upright. As the child gets better in cycling and his/hers stability gets better, the child doesn't need the training wheels anymore. They have fulfilled their purpose which was to help the child during the training process. As the learner's skills develop the need for scaffolding changes. It should be adjusted to meet the learner's needs by e.g. increasing it, decreasing it or changed in type.

Guidance on the other hand is not meant to be faded away as the learner's skills develop. Guidance is defined as complete and procedural information about how to perform the necessary sequence of actions and make the necessary decisions to accomplish a learning task (Clark, 2009). The terms are used quite literally in the literature, but in this thesis the term scaffolding is used to imply support that is meant to be faded away and the term guidance is used to imply a more permanent approach to support.

There is not a consensus on how teachers must use scaffolding and/or guidance to best aid in the learning process. It is suggested that scaffolding must only be provided when there is *"independent evidence that the learner cannot do the task or goal unattended"* (Pea, 2004). It also argued that guidance should be provided even when the learner could solve the problem without it because it is more effective and efficient to do so (Kirschner, Sweller, & Clark, 2006; Sweller, Kirschner, & Clark, 2007).

2.4 Peer group talk and collaborative work

In a peer group the students' talk is different from the teacher-student talk. The interactions are more symmetrical because the speakers are more or less equals. Peer discussions have been found to be more generative and exploratory than teacher-guided discussions (Hogan, Nastasi, & Pressley, 1999). On the other hand teacher-guided discussion was a more efficient way of obtaining higher levels of information even when the teacher didn't provide direct information to the students.

In science education peer group work is mostly used on practical investigations. These investigations can help the students to relate abstract ideas with the physical world. Computer-based activities can also be used for this purpose (Mercer, 2004). Research (Howe, Tolmie, Duchak-Tanner, & Rattray, 2000) has shown that in some cases computer-based activities are effective in promoting the development of scientific understanding but the discussion the students have while participating in the activity may not be productive and useful. On the other hand research (Arvaja, 2005) also suggests that the use of computer-based activities doesn't aid collaborative learning and the value of the activity is mostly to entertain students.

Working together in order to accomplish a goal is a way to scaffold learning (Dawes, 2004). The help of the more experienced peer aids all group members in the learning process. This is in unison with the ideas of the sociocultural perspective to learning and with Vygotsky's idea of the ZPD discussed in chapter 2.1. Nevertheless there are some problems with scaffolding learning with collaborative work (Dawes, 2004). Learners may not see the need to break the information into smaller pieces to help others develop their thinking. Learners are more likely to just provide the answer a problem than to help others figure it out themselves.

Research has shown that children's talk when working together is often uncooperative and unproductive (Galton & Williamson, 1992; Wegerif & Scrimshaw, 1997). In a Finnish study (Arvaja, 2005) students in the ages of 13 to 15 were found rarely engaging in cognitively high-level construction of shared understanding. When that did occur, the students had a clear task assignment that asked for reasoning. Relationships between students also had an impact on the collaboration. Friends worked better together than non-friends did. If other group members' ideas are not heard and acknowledged, the discussion soon deteriorates and becomes unproductive (Hogan et al., 1999). In science classes, students collaborating sometimes spend more time figuring out what to do when given a task than engaging in discussions that develop higher-order understanding (Hogan et al., 1999).

Collaborative learning in its best is engagement in dialogic talk in which the discussion in supportive and arguments are challenged (Dawes, 2004). Researchers strongly agree that this kind of talk requires target-oriented practise and new conversational skills to be taught (Dawes, 2004; Hannula, 2012). In science classrooms, these conversational skills include questioning, explaining, predicting, evaluating and deciding (Dawes, 2004). The study reported in this thesis looks into the quality of upper secondary school students' talk when they are working together in order to produce a drawing.

3. Drawing as a representation in science

3.1 Drawing as a representation

One type of visual representation is a drawing. While usually a drawing is seen as a work of art, in this thesis the term is used to imply also any graphs and/or explanatory words, which one uses in addition to the drawing[3].

Drawing can be defined as a process that is:

> *…ubiquitous, multi-purpose, multi-faceted, multimedia, multicultural and multi-meaningful*. -- (Hope, 2008, p.3).

Drawing is in fact a very multi-cultural mode of conveying information. Drawings can be understood by people from around the world, a feat that no language can match. This is also useful when working with people who have linguistic problems, e.g. children with learning disabilities. Drawings can also be used in school when the pupils are immigrants who don't yet have good language skills. In a sense, drawings can be used to get over the "language barrier".

When drawings are used to express learning, they allow the teacher to see and the student to reveal qualities of understanding that other methods may not reveal (White & Gunstone, 1992). This openness has a downside. Drawings are hard to grade reliably because reducing the drawing's rich data to a grade destroys information. A problem with using drawings as a representation is that they may easily be misunderstood (White & Gunstone, 1992). Other modes of representation, such as the mathematical mode, are so constraining that they are hard to misunderstand. Drawings' misunderstandings can be reduced by asking students to write explanations to their drawings. Drawings can also express understanding that is not expected (White & Gunstone, 1992). If students are evaluated using a closed test, the person making the tests makes choices about which parts of the phenomenon in question he/she wants to test. But when the

[3] In other words the term is meant to imply the visual mixed -group in Table 2

test is done using drawings, the understanding revealed from the students may be something unexpected.

3.2 The generative theory of drawing construction

A theoretical framework for understanding the cognitive process that happens when a learner is producing a drawing has been proposed (Van Meter & Garner, 2005). This framework is based on cognitive theory of the mind, not the sociocultural theory of knowledge construction discussed in chapter 2.1.

Let's imagine a situation where a student has to read a text and then is given a task to draw his/her conception about the subject of the text. First the student reads the text and forms an internal, verbal representation of the information in the text. The student picks elements from the text and organizes them to an internal model about the subject (R. E. Mayer & Gallini, 1990; Van Meter, Aleksic, Schwartz, & Garner, 2006). As proposed in chapter 1.1, any previous representations the student has observed about the subject complement this internal representation. When the student begins drawing, the internal verbal representation is used to activate stored nonverbal representations. For example, the word "a molecule" is used to activate the nonverbal representation of a molecule, e.g. the visual image of one. These nonverbal representations can be called *imagens* (Paivio, 1991). It's also possible that the student needs to nonverbally represent an object or an element of the text for which the learner has no imagen available (Paivio, 1991). In that case, the student produces a new imagen based on the verbal representation and uses that as the base of the drawing.

All in all, two internal representations, one verbal and one non-verbal, are needed before to student can produce an expressed visual representation about the text. This process of connecting two internal representations is called *mapping*. This process is necessary for the integration of representations (de Jong et al., 1998) and it's also likely an important part when determining the effectiveness of the drawing process (Van Meter & Garner, 2005). This mapping is unique to verbal – non-verbal- and non-verbal – verbal switching between representations. If the student is asked to e.g. make notes about the read text, that process doesn't require the integrations of different representations that use different modes because the read text and the notes are both part of the verbal mode of representation (Van Meter & Garner, 2005).

3.3 Drawing in science

Visual information is used in science to convey information to other scientists and to the public but also to make discoveries. This visual information includes diagrams, graphs, videos and photographs (Ainsworth, Vaughan Prain, & Tytler, 2011). But in science education, the focus is on interpreting drawings made by others. These drawings can be in the students' text books or they can be drawn by the teacher. Rarely students are asked to make their own visual representations (Van Meter & Garner, 2005). Some common findings for the use of learner-generated drawings can be found in literature (Van Meter & Garner, 2005). These findings are that drawing improves observational processes and it supports acquisition of content area knowledge. Drawing also improves text comprehension and facilitates the writing processes. Student affect is also improved using drawings as learning method.

Researchers argue (Ainsworth et al., 2011; Gilbert, 2005a) that the use of learner-generated drawings is an important part in becoming proficient in science and in learning what it's like to be a scientist. There are some issues considering the use of visual representations in comparison with e.g. textual representations in becoming scientifically proficient (G. R. Kress et al., 2001). Science teachers are likely to have an idea what a scientific text looks like. They know that scientific text uses the passive voice and the present tense among other qualities. In comparison, teachers don't have such a good knowledge on what makes a visual representation scientific. More emphasis is put on the linguistic than the visual. Visual representations are seen as an illustration of the accompanying writing. The visual area of *scientificness* hasn't been researched as much as it's textual counterpart (G. R. Kress et al., 2001).

A study was conducted about the scientificness of drawings (G. R. Kress et al., 2001, p.132). Two students examined the cells of an onion through a microscope. The students had to draw and write what they did and what they saw under the microscope. The researchers analysed the texts and the drawings for their scientificness. Student A wrote a text that was not deemed very scientific; it used the first tense and was more like a story about what was done. Student B's text was written using the conventions of a scientific text. The text used an impersonal voice and presented a step-by-step process on how to recreate the experiment. Still student A's drawing was deemed more scientific than Student B's. This small study shows that a student's scientificness can't be evaluated using just one mode of representation. The suggestions considering the importance of multiple representations on science education introduced in chapter 1.1 also support this argument.

Teachers sometimes have difficulties in guiding students to draw a scientific representation about what they see. A case like this was reported in a study (Scott & Jewitt, 2003). The researchers observed a physics lesson where the subject at hand was magnetic fields and the drawing of the magnetic field lines. The observed teacher had trouble using correct vocabulary to aid the students in their drawing assignments. For example the word "pattern" had different meanings to the teacher and to the students. It seems that the students need to learn to "see science" (Scott & Jewitt, 2003). In the study the teacher was talking about how to draw the magnetic field lines. The teacher is aware of the scientific conventions of drawing magnetic field lines and tries to explain to the students the differences in their drawings and the conventional drawings. The problem is that the students don't yet know the conventional way of drawing magnetic field lines. They don't know the theory behind the conventions which would serve as a representational filter to guide the students in their drawings.

Drawing is a very important part in understanding e.g. the previously mentioned subject of magnetic fields (Scott & Jewitt, 2003). They provide the students a physical representation to think about and to think with (Ogborn, Kress, Martins, & McGillicuddy, 1996). Magnetic fields are a concept that can't be really be seen unless visually represented in some way. It is important for teachers to explicitly point out the differences between what is seen by the naked eye and what science sees. The real world isn't the same as the scientific world.

3.4 The need for guidance in drawing

Proper guidance helps the learner to develop strategies to apply to different problems. Guidance should not be used to give answers to specific questions, because it doesn't help the learner when dealing with other similar problems (Bodrova & Leong, 1998). In drawing, this means that the guidance should be such that it helps the learner to draw in a way that is helpful to the whole learning process. The guidance should not be direct instructions on what to draw in a particular situation. While it may be useful in that particular assignment, it doesn't help the learner in his/hers next drawing assignment without similar support.

If a learner is asked to draw his/her conception about a particular subject, different types of guidance can be used to help the learner in the learning process. The two sides of the support continuum are "free draw" and "explicit instructions". The learner can be provided only with instructions to construct a drawing. On the other hand, learners can also be given explicit instructions on what to draw (Van Meter & Garner, 2005). Studies have partially shown that some kind of support in the drawing process is needed to achieve an effective drawing strategy (Van Meter & Garner, 2005).

A meta-analysis of learner-generated drawings and the need for support in them has been published (Van Meter & Garner, 2005). In the meta-analysis of the research in the subject three different functions for support in drawing can be found:

1) Support helps the student by constraining the construction of drawings (Lesgold, Levin, Shimron, & Guttmann, 1975).

2) Support prompts students to check the accuracy of constructed drawings (Van Meter, 2001).

3) Support directs the learner's attention to key elements in the subject and to their relationships (Alesandrini, 1981).

It's interesting to note that these functions are very similar to the ones Ainsworth has named for multiple representations (Ainsworth, 1999a; Ainsworth, 1999b; Ainsworth, 2006; Ainsworth, 2008). These functions were discussed in chapter 1.1. Multiple representations can be in different modes e.g. in the verbal mode and in the visual mode, but also in the same mode. A support method sometimes used with drawing is the comparison of the learner-generated drawing to a provided drawing (Van Meter, 2001;

Van Meter et al., 2006). The learner-generated drawing is drawn using and selecting information from a provided text. In that case, the learner has access to three different representations: the provided text, the learner's drawing and the provided illustration. The provided illustration can be used to constrain learner-generated drawings, it can be used to check the accuracy of those drawings and it can also be used to direct attention to key elements.

3.5 Empirical studies about guidance in drawing

Some research has been done on guidance in drawing (Van Meter, 2001); (Van Meter et al., 2006). In one study, fifth and sixth graders read a two-paged text about the human nerve system (Van Meter, 2001). The students were divided into four groups. The first group was a read-only control group who only inspected the provided illustrations but didn't draw anything. The second group was a drawing group who drew a drawing without support after each page which represented that they thought to be the important ideas in the page. The third group was an illustration comparison (IC) group who compared their drawings to a provided illustration without exact instructions. The last group was a prompted illustration comparison group (PIC) who compared their drawings to provided illustrations and responded verbally to provide questions intended to direct the comparison process. The students' learning was measured using free-recall and recognition posttests. Drawing accuracy was also evaluated and the students self-monitoring events (lookback, hesitation etc.) were observed. Also the time spent on reading and drawing was observed. The results showed that the PIC group drew more accurately than the IC group, who in turn drew more accurately than the draw-only group. When learning was measured using the free-recall posttest, the PIC group got significantly higher scores than the IC or draw-only groups. The read-only control group got much lower scores than any other group. In the recognition posttest, the differences between groups were below the confidence level.

In another study, fourth and sixth graders read about wings of birds (Van Meter et al., 2006). The students were again divided into four groups: a control group, drawing group, illustration comparison group (IC) and prompted illustration comparison group (PIC). The assignments to each group were similar to the 2001 study. Before the assignments the students' knowledge about the subject was tested using a pretest. After the assignments students' learning was measured using problem solving and multiple-choice recognition posttests. The results showed that the sixth graders in the IC and PIC groups scored higher in the problem solving posttest than the control group. The difference between the drawing group and the control group was statistically significant. With the fourth graders the differences between the groups were not statistically significant. Drawing even with support didn't increase problem solving scores for the fourth graders. In the multiple-choice posttests the difference between the groups was not statistically significant in both grades.

In the reported studies, drawing did increase the learning results most of the time. The benefits of guidance were only apparent in higher-level assignments, such as problem solving assignments.

It is interesting to note that the fourth graders didn't benefit from drawing and increasing levels of support. The researchers dismiss the hypotheses that prior knowledge or general comprehension skills had anything to do about that fact. In the pretest the fourth graders even scored slightly higher than the sixth graders. General comprehension skills were also similar in both grades because the control groups scored nearly identically on the posttests. The researchers note that drawing operates differently for younger learners. They call for further research to test these findings and to find out more about the age-related differences. The study reported in this thesis aims to study the benefit of support with upper secondary school students.

4. Tablet computers and education research

4.1 What is a tablet computer?

The word *tablet* is defined in computing as *"an input device that allows the user to draw or write freehand to screen by means of stylus or digital pen"* (Collins English Dictionary - Complete & Unabridged 10th Edition, 2013). A *tablet computer* is then a computing device that allows the user to draw or write to the screen. The dictionary's definition for the word tablet is already quite old-fashioned, because modern day tablet computers allow the user to draw to the screen using only ones fingers. It means that the input method is natural and doesn't require any other devices such as special pens.

Tablet computers usually have a screen that is from 7'' to 10'' big. They have at least a camera on the back and maybe another on the front. The tablet also has microphones to record sound and acceleration sensors which are used to rotate the screen when the device is rotated. The sensors can also be used for other purposes. Users can write their own applications for their tablets. These applications enable the devices to be used in a multitude of ways.

Nowadays the most sold tablet computer line on the market is the Apple iPad line, which had a 43.6% market share in the fourth quarter of 2012 (Mirror News, 2013). The product line had sales of 22.9 million tablet computers in the final three months of 2012. The next most sold line of tablet computers is Samsung's Galaxy line, which had sales of 7.9 million and a market share of 15% in the same period of time.

4.2 Tablet computers compared to other devices

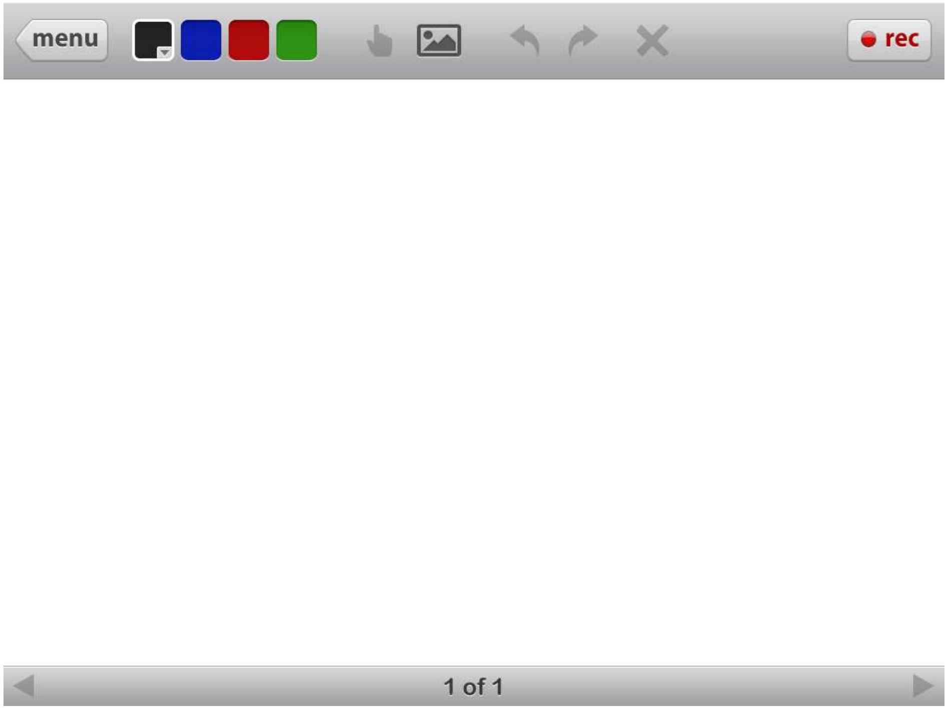
Tablet computers usually support multi-touch. It means that the tablet's screen accepts more than just one touch at a time. This combined with the size of the screen enables the device to be used by multiple people at the same time. When using a single-touch device or a conventional laptop, people have to take turns in using the device. This can lead to some people dominating the technology while more passive people are left without a chance to participate in the use of the device. This leads to a loss in learning benefits from group exercise for the more passive people (Harris et al., 2009). Multi-touch devices can reduce this inequality because the students can interact with the device at the same time. This has been shown to increase engagement with the device (Rick et al., 2009).

Notebooks and laptops are operated by a keyboard and a mouse or a trackpad. These methods are not as natural to humans as drawing using ones fingers. Fingers are also a natural way to utilize the multi-touch screen; we have five fingers that can be used to e.g. move objects on the screen. The possibility to use fingers as method of controlling the computer helps also when the tablet computer is used in learning. The students feel more motivated and interested to learn. They are also more engaged with the content at hand which keeps the students interested in learning for a longer period of time (Agostini, Di Biase, & Loregian, 2010).

Tablet computers also have additional sensors compared to notebooks and laptops. Tablets usually have at least one camera and acceleration sensors. Some devices also have an integrated GPS chip for positioning. These sensors and chips give tablet computers new ways to be used in education and science education in particular. Many applications have been written that enable tablet computers to be used as a scientific measure device. Tablet's camera can be used as a lux meter to measure illuminances with a special application (Apple, 2013; Google, 2013). An application also exists that enables the acceleration sensors on the device to be used as a gyroscope and a spirit level (Apple, 2013). The large touchscreen also enables the device to be used as a drawing board, a function that is studied in this thesis.

4.3 The Educreations application

This thesis deals also with using tablet computers in education research. In particular an application for the iPad called Educreations (Apple, 2013) is examined. The application's website (Educreations, 2013) states that the goal of the app is to let anyone teach what they know and learn what they don't. This is accomplished by enabling the users to make animated lessons which can contain pictures, drawing and speech. Below is a picture of the applications user interface (Picture 1):



Picture 1: The user interface of the Educreations application

When the user presses the record button, the application begins to record everything that is drawn on the screen and everything that is said to the microphone. The user can change drawing colours, add images to the screen and change pages. When the recording is over, the user can share the animation with every user of Educreations, with just a selected number of people or the animation can be marked as private.

One of the reasons the Educreations application was used in this study was that it enabled the simultaneous recording of the students' drawings and their talk. If the drawings and the talk were recorded separately, they would have to be combined together using time codes. Using the Educreations application the output was one animation that had everything this study required. The use of external recording equipment could have also impacted the behaviour of the students. With the application it sometimes seemed like the students didn't even remember the recording was on. Another reason for the use of the application was that it enabled the observation of the whole drawing process. In some cases the students drew something and then were not satisfied with it which resulted in its erasure. If the drawings were collected by paper, the researcher would have only seen the final results, not the intermediary steps in the drawing process.

Because the application is not designed for education research, it has some drawbacks compared to traditional research methods. An important part of communication is the use of gestures (Jewitt et al., 2001). It can be heard in the peer talks recorded for this study when the students are talking about “that thing over there” and at the same pointing at the thing. Because the application doesn’t record video of the users, the researcher can’t be sure about the thing the students are talking about. This could be solved using an external camera or maybe even the built-in front camera on the tablet. The drawing tools were also very limited. There are only 10 colours to use and only one line width. In the versions used in the study (versions 1.2 and 1.3) the user couldn’t even use the eraser. The only choice to get rid of something was to undo the last line drawn. The ability to use an eraser was added only in version 1.4.

All in all, the use of any similar application with a tablet computer could serve the same purpose. Educreations was chosen because it was available on the iPad and the school in which the study was conducted used iPads. If someone was passionate about using iPads in education research, they could code a better application. In the meantime Educreations is a “good enough” choice.

5. Pressure and the kinetic theory of gases

The subject for the students' drawings was chosen to be the kinetic theory of gases and the ideal gases. This subject was chosen because it's a subject which is usually taught using plenty of text book illustrations (Hatakka, Saari, Sirviö, Viiri, & Yrjänäinen, 2005). The possibilities for drawing in teaching the kinetic theory of gases have been tested before. In a study, all eleven primary school teachers drew the movement of the gas particles according to the kinetic theory of gases correctly even though they had problems with applying the theory to solve problems (Robertson & Shaffer, 2013).

Because the concept of pressure is closely related to the kinetic theory of gases, it's necessary to get a more physical insight into these concepts. Misconceptions related to the concept of pressure are also reported. The knowledge of the physical background behind the students' drawings' gives the chance to compare the students' models about e.g. pressure with the theory. This mathematical representation of pressure is also a part of the "language of physics". The students' drawings' are another representation about the same subject, represented through another mode of representation.

5.1 The definition of pressure

Pressure p is defined (Young & Freedman, 2000, p.429) as follows: Consider a small surface of area dA centered on a point in the fluid (either gas or liquid). The normal force exerted by the fluid on each side is dF. Pressure p in that point is defined as the normal force per unit area

$$p = \frac{dF}{dA}.$$

Equation 1: The formal definition of pressure in a fluid

If the pressure is uniform at all points of a finite plane surface with area A then

$$p = \frac{F}{A}.$$

Equation 2: The most commonly used definition for pressure

5.2 The kinetic theory of gases

In the kinetic theory of an ideal gas assumes that the particles in an ideal gas are in constant motion and that they collide occasionally and perfectly elastically with the walls of the gas container (Young & Freedman, 2000, pp. 507-509). These collisions exert forces on the walls and they are the origin of the pressure the gas exerts. It can be shown that the pressure of the gas depends on the amount of gas particles, the temperature and the volume of the gas.

First, let v_x be the average magnitude of the x-component of a particle of the gas and let m be the mass of a particle. The particles don't all move at the same velocity but one can use the average velocity instead. When a particle collides with a wall perpendicular to the x-direction, the x-component of the velocity changes from $-v_x$ to v_x. So the x-component of the momentum changes from $-mv_x$ to mv_x and the total change in the x-component of the momentum is $(mv_x) - (-mv_x) = 2mv_x$.

If a particle is going to collide with a given wall area A during a small time interval dt, the particle must be within a distance of $v_x dt$ from the wall at the beginning of the time interval. It must also be headed towards the wall. On average, half of the particles are moving towards the wall and half are moving away from it. The number of molecules that collide A during a small time interval dt is half of the number of the particles within a cylinder with base area A and length $v_x dt$. The volume of such cylinder is $Av_x dt$. Assuming the number of particles per unit volume (N/V) is uniform, the number of particles that collide with A during dt is

$$\frac{1}{2}\left(\frac{N}{V}\right) \quad (Av_x dt).$$

Equation 3: The number of particles that collide with *A* during a small time interval *dt*

For all particles in the gas the total momentum change dP_x during dt is the number of collisions multiplied by the momentum change in one collision

$$dP_x = \frac{1}{2}(\frac{N}{V}) \quad (Av_x dt) \ (2mv_x) = \frac{NAmv_x^2 dt}{V}.$$

Equation 4: The total momentum change in the gas during a small time interval *dt*

According to Newton's second law, the rate of change of momentum equals the force exerted by the wall are A to the gas particles and according to Newton's third law this is also equal to the force exerted by the gas particles to the wall. Pressure p is the magnitude of the force exerted on the wall per unit area

$$p = \frac{F}{A} = \frac{\frac{dP_x}{dt}}{A} = \frac{\frac{NAmv_x^2}{V}}{A} = \frac{Nmv_x^2}{V}.$$

Equation 5: The pressure of a gas with a volume of *V* and with *N* molecules each with a mass of *m* and with an average speed of v_x

Because the movement speed of the particles is dependent on the temperature of the gas, the pressure of the gas depends on the amount of gas particles, the temperature of the gas and the volume of the gas.

5.3 Misconceptions about pressure

Students' misconceptions about pressure have been studied extensively (Fassoulopoulos, Kariotoglou, & Koumaras, 2003; Kariotogloy, Psillos, & Vallassiades, 1990; Kautz, Heron, Loverude, & McDermott, 2005; Kautz, Heron, Shaffer, & McDermott, 2005; Ozmen, 2011; Robertson & Shaffer, 2013; Tytler, 1998). One main misconception that rises from research is that students do not discern pressure from force (Fassoulopoulos et al., 2003; Kariotogloy et al., 1990) or in broader terms, *intensive* quantities from *extensive* quantities (Fassoulopoulos et al., 2003). In physics, quantities like force or area whose value is dependent on the size of the system they are referring to are called extensive quantities (Mandl, 1988, p.44). On the other hand, quantities like pressure that are independent from the size of the system are called intensive quantities. Intensive quantities are defined by the quotient of two extensive quantities, for example pressure = force/area. In one study only 17% of 12 to 15 year old Greek students consistently understood pressure as an intensive quantity (Fassoulopoulos et al., 2003).

Another difference between pressure and force is that pressure is a scalar quantity (it has no direction, only a value) and force is a vector quantity (it has a direction and a value). At least in the 1970's and 1980's physics textbooks used in secondary and tertiary education had difficulties explaining the difference (Kariotogloy et al., 1990). Textbooks had phrases like "the upward pressure" which could cause confusion. It seems that nowadays the situation may be better. At least one physics text book used in universities explicitly states that force is a vector and pressure is a scalar (Young & Freedman, 2000, p. 429).

In research done in the United States, more than 1000 university physics students were involved in a study that investigated students' conceptions about the ideal gas law (Kautz, Heron, Loverude et al., 2005; Kautz, Heron, Shaffer et al., 2005). Some of the misconceptions reported were that pressure is always dependent on and inversely proportional to volume and pressure is always dependent on and directly proportional to temperature (Kautz, Heron, Loverude et al., 2005). There were also problems relating the kinetic theory of gases to gas pressure. Between 25% to 40% students had problems associating the change in the particle flux with the change of pressure (Kautz, Heron, Shaffer et al., 2005). More than one-third of the students held a misconception that a greater number of lighter particles are needed to produce a given pressure (Kautz, Heron, Shaffer et al., 2005). They didn't remember that in an ideal gas the gas particles are assumed to be point-like. There were also difficulties in dealing with the change in momentum in a particle's collision and with the conservation of momentum (Kautz, Heron, Shaffer et al., 2005).

Younger children between the ages of 6 and 12 had difficulties with the concept of atmospheric pressure because one can't observe its effects because the air pushes us from every direction with the same force (Tytler, 1998). Young children also don't have the necessary knowledge about air and its properties or about associated conceptions such as force and pressure.

6. Research questions

In the preceding chapters I have described the theoretical background of the study. The theory deals with different representations and especially drawing as a representation, sociocultural views of learning, scaffolding and guidance, tablet computers and the concepts of pressure and the kinetic theory of gases. The main view of learning presented in this thesis is a sociocultural one, but aspects of individual view of learning are also taken into account in chapter 3.2 about the generative theory of drawing construction (Leach & Scott, 2003).

The research questions are the following:

1. How do upper secondary school students use drawing as a tool for meaning-making in physics?

2. Does guidance influence the drawings that upper secondary school students produce?

3. What kind of talk do upper secondary school students use when they are engaged in a meaning-making process?

4. What possibilities does using a tablet computer bring to education research?

Based on the research discussed in chapter 3.5, the research hypothesis for research question number 2 is that guidance in the form of drawing comparison aids the students in some ways in their own drawing process. The research hypothesis for research question number 3 is that the students' talk is generally unproductive and of low value based on the research discussed in chapter 2.4. Research questions number 1 and 4 are exploratory in their nature, because there isn't any direct research done relating to these questions.

7. The study

7.1 The outlines of the study

The study was conducted in the spring of 2013 in a Finnish upper secondary school located in a medium sized city. The participants of the study were upper secondary school students studying their second year aged between 17 and 18. The students were both male and female. The study was conducted within an optional physics course, so the students in the course were in some way interested in physics. There are eight courses of physics that you can take in Finnish upper secondary schools (Finnish National Board of Education, 2003, p.148). These courses consist of 38 lessons which last for at least 45 minutes. One course in physics is mandatory and the other 7 are optional. Most of the participated students had completed five courses in physics. Most importantly the students had completed a course on thermodynamics approximately one year before the study was conducted. That means the students had learned about ideal gases and the kinetic theory of gases before. This gave a chance to study the effect of previous teaching on the drawings.

The study was conducted with two different student groups. The students were paired up randomly with another classmate. If the student group had an odd number of students then one group had three students. The pairs and groups of three were divided into two different categories: the "assisted group" (AS) and the "unassisted group" (UA). The UA group and AS group were in different rooms. In the first student group six pairs and one group of three participated. Three pairs were assigned to the AS group and three pairs and the group of three were assigned to the UA group. In the second student group nine pairs and one group of three participated. Five pairs were assigned to the AS group and four pairs and the group of three were assigned to the UA group. All in all 36 students took part in the study.

The actual study was conducted using a study form (see Appendix 1).The study form consisted of two different parts, part A and part B. The differences in the assignments are presented in a figure below (Figure 3):

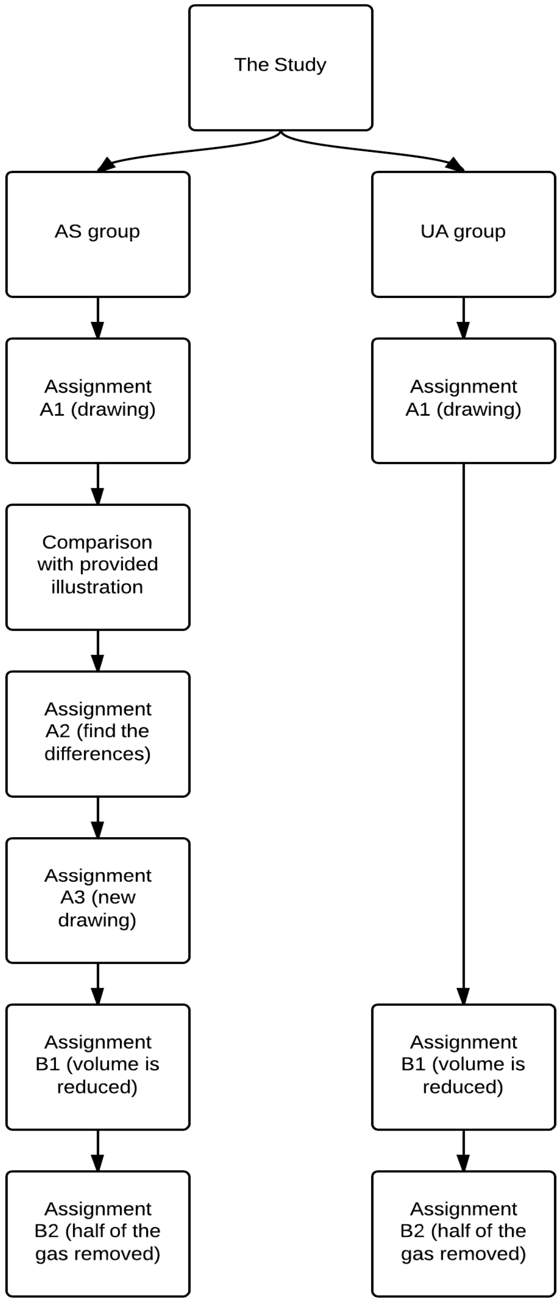


Figure 2: The two groups and the different assignments for them in the study

In part A, the students read a short text (see Appendix 1) about the kinetic theory of gases and the concept of the ideal gas. The text was followed by assignment A1 in which the students were instructed to draw their conception about the kinetic theory of gases. After assignment A1 only the students in the AS group continued to part A and the UA group continued to part B. The AS group were shown a drawing made using the Educreations application. The students were instructed to compare the provided drawing with their own. In assignment A2 the students had to find the possible differences between their own drawing and the provided one. The final assignment of part A was assignment A3 in which the students were instructed to draw a new drawing about the subject as in assignment A1 using the information they may have received by examining the provided drawing.

Part B was similar for both groups. In assignment B1 the students had to draw their conception on what happens when the volume of the gas container is reduced compared to assignment A3 (AS group) or A1 (UA group). In assignment B2 the students had to draw their conception on what happens to the gas when half of the gas is removed from the gas container.

The study took about 45 minutes to conduct. That time includes the explanation of the study procedure to the students. The lengths of the videos produced by the students ranged from 3 minutes 59 seconds to 15 minutes 17 seconds for the UA group and from 3 minutes 49 seconds to 13 minutes 45 seconds for the AS group. The average lengths were 7 minutes 42 seconds for the UA group and 9 minutes 37 seconds for the AS group. The students could pause the recording while reading the study form, this explains the shorter video lengths compared to the length of the whole study.

Students used third generation iPads for the drawing. These tablet computers were supplied by the school. The application Educreations was installed on the devices. Day before the study, the students had a brief session in which they were instructed on how to use the application for drawing. They also had a bit of time to explore the application. The students knew the basics on how to operate a tablet computer and didn't require any help with it.

7.2 Method for the study of the students' talk

The students' talk was analysed using a typology (Mercer, Dawes, Wegerif, & Sams, 2004) developed in the 1990's for categorizing children's talk. The three categories in the typology are *disputational talk, cumulative talk* and *exploratory* talk. Disputational talk is sometimes even hard to see as a conversation, because sometimes the ideas of one or more speakers are left unheard or they are given no value (Alftan, 2012). Cumulative talk is most common when the speakers are working together and are trying to finish the task as quickly as possible. Because ideas are not backed up with reasoning, cumulative talk is not very beneficial for learning. In contrast to cumulative talk, in exploratory talk the speakers have to give reasons for their ideas. That helps both the speaker and the listeners to discern their ideas and aids in learning. Exploratory talk can be seen as a combination of disputational talk and cumulative talk retaining the alternative hypotheses from disputational talk and the cooperation from cumulative talk (Wegerif & Mercer, 1997). These three categories and excerpts from the study data are presented below (Table 3):

Table 3: A typology of children's talk (Mercer, 2004) **and excerpts from the study data.**

Name of the category	**Additional information about the category**	**Group number and an excerpt from the study data**
Disputational talk	Speakers disagree about something and make decisions individually. The talk is not very constructive and it can consist mainly of short exchanges of assertions and challenges.	(Group AS 5) Student A: *Can I try to draw a three-dimensional cube?* Student B: *OK try to draw a cube (Student A begins to draw)* Student B: *I don't know if there's any sense drawing it three-dimensional because it's just a model so it can be two-dimensional-* Student A: *Nonsense I did it already* B: *OK*
Cumulative talk	Speakers agree about the subject at hand. The talk is positive but uncritical. The speakers repeat what the others have said and confirm their ideas.	(Group AS 8) Student C: *Well here is now half as much of the gas so I could say that-* Student D: *There are less-* C: *Less collisions on the walls so could we say that the total force-* D: *Pressure… when they create the pressure there-* C: *Yes it is smaller than in that one… where there are more of those… gas molecules*
Exploratory talk	Speakers challenge each other's ideas critically but constructively. Suggestions are offered for the whole group to consider. The opinions of the speakers are justified out loud and alternative hypotheses are offered.	(Group AS 5) Student E*: Then let's draw their trajectories* Student F: *Yes or then… I was wondering if we could do it this way… draw like a circle there where a few of them shows and then lines here and there… here comes a bigger circle in which you draw a few dots and then the lines to those so that we don't have to…* E: *Yes it could be difficult, it's easier that way, you do it that way*

The first excerpt is an example of disputational talk because students A and B are disagreeing about whether they should draw a two- or three-dimensional cube where the particles are. B's argument that the third dimension is unnecessary is discarded by A and he/she just decides to draw it three-dimensionally. The second excerpt is an example of cumulative talk because the students are repeating what the other has said. They are also building the conversation on top of the other speaker's words and are interrupting each other constantly. The third excerpt is an example of exploratory talk because when student E says that they should simply draw the trajectories of the particles, student F has a better idea which he/she begins to verbalise. F doesn't reject E's initial idea outright, but begins to show him/her an alternative way of picturing the particles' movement. In the end E is convinced by F's argument and they go with it.

The students' talk was transcribed using Transana v. 2.52 (University of Wisconsin-Madison Center for Education Research, 2012) and the transcripts were exported to ATLAS.ti v. 7.0.89 (ATLAS.ti Scientific Software Development GmbH, 2013). ATLAS.ti was used to code the transcripts and the drawings. The division of the talk into three different categories is not a simple task. Different people may have different ideas on what amounts as e.g. exploratory talk. In this study the validity of the coding was checked by using the help of an outside referee. He/she was a just graduated Doctor of Philosophy who has specialized in studying students' and teachers' dialogue. He/she coded one of the transcripts him/herself and the codings were checked against each other. The reliability was found to be 75% using this equation

$$reliability = \frac{number\ of\ agreements}{total\ number\ of\ agreements + disagreements}\ .$$

Equation 6: An equation to check the reliability of coding (Miles & Hubermann, 1994)

The students' talk and drawings were analysed separately, but the link between the two was used when necessary. For example, when a student said "Now this collides with that" while drawing, what "this" and "that" were could be deduced from the drawing made at the same time.

7.3 Method for the study of the student's drawings

Before the study was conducted, five criteria for a good drawing about the kinetic theory of gases were chosen by the author of this thesis. These are not the absolute best criteria for a good drawing about the subject because everyone has their own unique background (education etc.) which affects the selection. The selected five criteria were:

1. The particles should be point-like or as small as possible to draw.

2. The particles should be illustrated as being in a random motion.

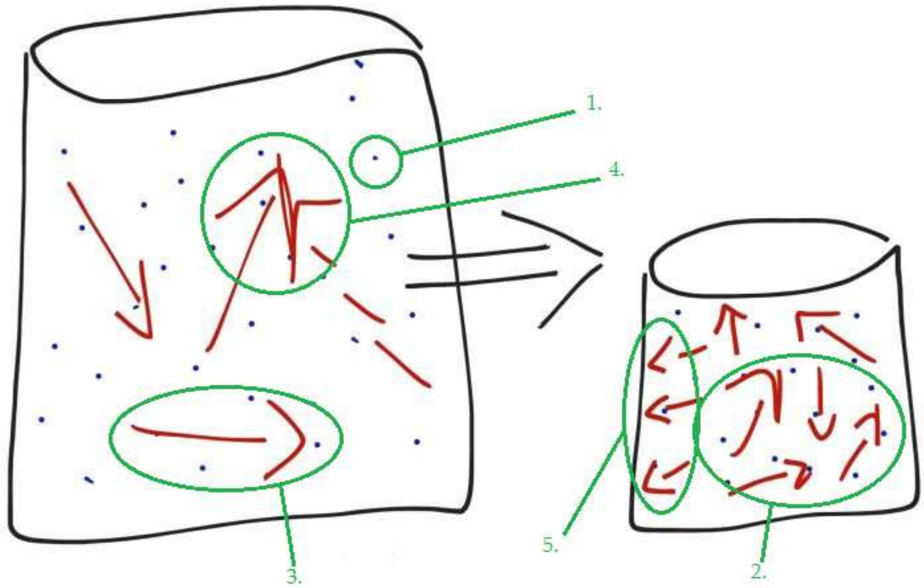
3. The particles should be illustrated as being in a rectilinear motion.

4. The particles should be illustrated as colliding with each other.

5. The particles should be illustrated as colliding with the walls of the container.

The appearance of these five criteria in the drawing are analysed qualitatively, based on the researcher's conception about what amounts as e.g. colliding particles. These findings are counted and the counts are analysed quantitatively using statistical methods. This approach mixes qualitative analysis with quantitative analysis.

Following is an example of a drawing from assignment B1 and from the group UA 6 that illustrates all of the five criteria (Picture 2):



Picture 2: An example of a drawing from group UA 6 that illustrates all of the five criteria for a good drawing about the kinetic theory of gases. The green circles and numbers have been added and they correspond with the numbering on the previous page.

As one can see, analysing the drawings is not an unambiguous task. The underlying problem in all qualitative research is that the researcher can never have a truly objective view on the research subject (Denzin & Lincoln, 2005, p.21). The researcher's language, gender, social class, race and ethnicity affect the conceptions of the researcher. A background as a physics student affects the views on what amounts as e.g. rectilinear motion. This is comparable to the problems discussed in chapter 2.2 about sociocultural discourse analysis. As discussed in chapter 3.1, the openness of drawings as an expressed model leaves plenty of room for interpretation. One thing that helps with the analysis could be the students' talk associated with the drawing. The students' talk is used in the analysis of the drawings only when necessary to explain them.

7.4 Methods for answering the research questions

The research questions discussed in chapter 6 are presented below (Table 4). With them are listed the data used to answers those questions and the methods used in the analysis:

Table 4: The research questions, the data that was analysed and methods used in the analysis

The research question	The data	The method of analysis
How do upper secondary school students use drawing as a tool for meaning-making in physics?	Students' drawings	Data based
Does guidance influence the drawings upper that secondary school students produce?	Students' drawings	Data based / qualitative content analysis
What kind of talk do upper secondary school students use when they are engaged in a meaning-making process?	Students' talk	Mercer, Fisher and Dawes' typology from chapter 7.2
What possibilities does using a tablet computer bring to education research?	Student's drawings and talk	Impressions from the study

Both qualitative and quantitative methods were used in the analysis. The study method used can be called *qualitative content analysis* (Chi, 1997) or a type of a *mixed method* called *exploratory design* (Creswell & Plano Clark, 2007). The data was analysed qualitatively and coding was used to e.g. to code the different categories of the students' talk or to code the appearance of five criteria from chapter 7.3 in the students' drawings. These results are then studied in more detail quantitatively. The method used in this study also has aspects of a *case study*. The study investigated a contemporary phenomenon within it real-life context and relied on multiple sources of evidence (Yin, 2008). Prior theoretical development was used to guide data collection and analysis.

The students' drawings were analysed using a *data based* method which had some similarities with another method called *grounded theory.* This research method came into existence in 1960's (Glaser & Strauss, 1965). The method differed from grounded theory by the amount of background research. When using a grounded theory method, the researcher should approach the subject with limited background knowledge or literature review (Bryant & Charmaz, 2007). I had done some background research before the study was conducted so the approach was not that of grounded theory's. Grounded theory methods revolve around the research data (Bryant & Charmaz, 2007). Grounded theory aims to develop theoretical explanations for the empirical findings. These explanations or theories are grounded on the research data.

8. Results

8.1 Quantitative analysis of the drawings

The drawings for each assignment were analysed for the appearance the criteria discussed in chapter 7.3. Both the possible text accompanying the drawing and the drawing itself were taken into account. The results are presented below (Table 5):

Table 5: The number of pairs or groups of three in each group (UA or AS) that had the demanded criteria in their drawings

Assign.	Group	Point-like	Random motion	Rectilinear motion	Collisions between particles	Collisions with walls
A1	UA n = 8 AS n = 9	6 7	7 8	5 8	3 4	8 6
A3	AS n = 8	7	8	8	6	8
B1	UA n = 8 AS n = 9	6 8	6 8	4 9	1 2	5 9
B2	UA n = 8 AS n = 9	6 6	4 7	4 9	0 2	3 8

Because the frequencies in each category were too small for statistical purposes, the five categories were combined into two main categories: 1) particles are drawn as point-like and they move randomly and rectilinearly and 2) particles collide with the each other and with the walls of the gas container. The first main category is related to the students' ability to visually represent the particles' size and movement and the second main category is related to the ability to visually represent the particles' collisions. The results divided into the main categories are presented below (Table 6):

Table 6: The frequencies of the five criteria in each group (UA or AS) combined into two main categories

Assign.	Group	Point-like, random motion and rectilinear motion	Collisions between particles and with the walls of the gas container
A1	UA AS	18 23	11 10
A3	AS	23	14
B1	UA AS	16 25	6 11
B2	UA AS	14 22	3 11

The combining allows statistical methods to be used. The method used is as follows: The observed and expected frequencies of the five criteria in each of the assignments (A1 and B1 & B2) and in each of the two main categories are tabulated. The observed and expected frequencies of the criteria missing from the maximum amount are also tabulated with them. The null hypothesis was that the criteria and the missing criteria should be distributed evenly between the UA and AS groups, taking into account the fact that the groups have different amounts of members in them. The frequencies of the criteria and the missing frequencies of the criteria are presented in tables below (Table 7 - 10):

Table 7: The observed and expected frequencies of the point-like, random motion and rectilinear motion criteria from assignment A1 with the missing frequencies

Assignment A1, point-like, random motion and rectilinear motion	UA group, max = 24	AS group, max = 27
Appearances of the criteria	18 (19.294)	23 (21.706)
Missing criteria	6 (4.706)	4 (5.294)

Table 8: The observed and expected frequencies of the collisions between particles and with the walls of the container criteria from assignment A1 with the missing frequencies

Assignment A1, collisions between particles and with the walls of the container	UA group, max = 16	AS group, max = 18
Appearances of the criteria	11 (9.882)	10 (11.118)
Missing criteria	5 (4.078)	8 (6.882)

Table 9: The observed and expected frequencies of the point-like, random motion and rectilinear motion criteria from assignments B1 & B2 with the missing frequencies

Assignments B1 & B2, point-like, random motion and rectilinear motion	UA group, max = 48	AS group, max = 54
Appearances of the criteria	30 (36.235)	47 (40.765)
Missing criteria	18 (11.765)	7 (13.235)

Table 10: The observed and expected frequencies of the collisions between particles and with the walls of the container criteria from assignments B1 & B2 with the missing frequencies

Assignments B1 & B2, collisions between particles and with the walls of the container	UA group, max = 32	AS group, max = 36
Appearances of the criteria	9 (14.588)	22 (16.412)
Missing criteria	23 (17.412)	14 (19.588)

The χ^2-test was conducted using the observed and expected frequencies of the criteria for assignments A1, B1 and B2. The p value of ≤ 0.05 was considered statistically significant. The effect sizes were estimated using Cramer's V where 0.1 = small effect, 0.3 = medium effect and 0.5 = large effect (Clark-Carter, 2010, p.301). There was little difference between the groups in assignment A1 which tested the students ability to draw before the guidance was applied [$\chi^2 = 0.359$, $p = 0.549$; Cramer's V = 0.084 for the point-like, random motion and rectilinear motion categories and $\chi^2 = 0.19$, $p = 0.663$; Cramer's V = 0.075 for the collisions between particles and between the walls of the gas container categories]. The difference is not statistically significant. The χ^2-test showed that the presence of guidance had an small to medium effect on the quality of the drawings in assignments B1 and B2 [$\chi^2 = 6.754$, $p = 0.009$; Cramer's V = 0.257 for the point-like, random motion and rectilinear motion categories and $\chi^2 = 6.161$, $p = 0.0131$; Cramer's V = 0.301 for the collisions between particles and between the walls of the gas container categories]. The difference is statistically significant.

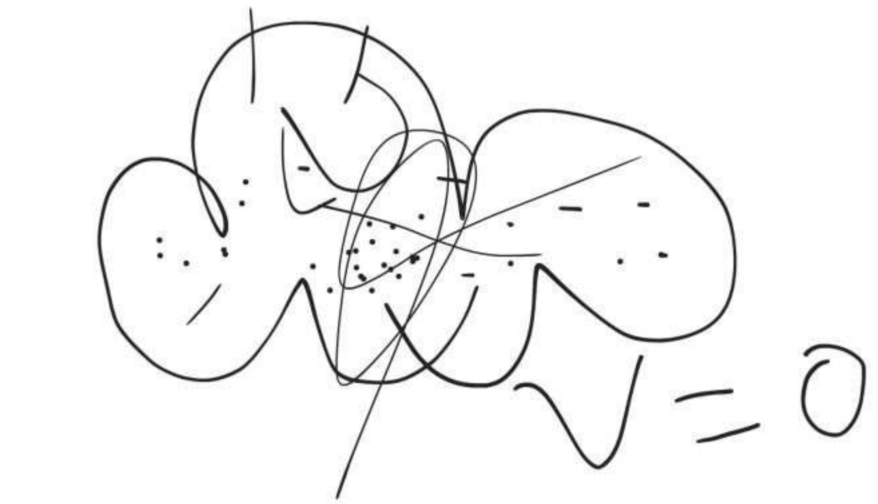
8.2 Qualitative analysis of the drawings

8.2.1 Assignment A1

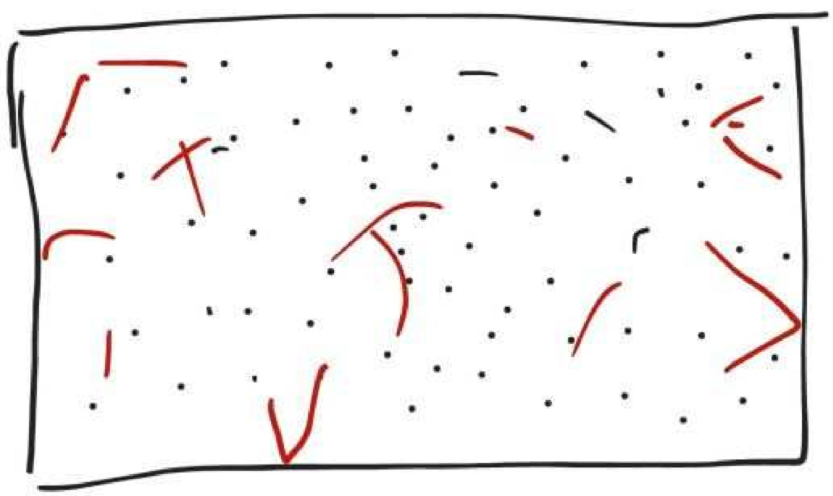
There were no major differences between the AS and the UA group in assignment A1. That was to be expected, because the groups were selected randomly from the same classes.

Even though the assignment A1 didn't require the illustrated gas to be in a container, still 13 out of 17 pairs or groups of three chose to represent ideal gas in a container. The text that the students read also mentioned the collisions with the container walls, but nowhere was it mentioned that the gas should be in a container. Illustrating gas particles moving in a container could be viewed as the traditional type of an illustration about the kinetic theory of gases at least in Finnish physics text books (Hatakka et al., 2005). One can see the influence of the text book illustrations in most of the drawings to A1.

Following are examples of students' drawings to assignment A1 from two different groups. The first drawing illustrates gas particles being in a cloud and the latter illustrates them being in a container (Picture 3 & Picture 4):



Picture 3: An example drawing from assignment A1 from group AS 9 with the gas in a cloud. V = 0 implies that the volume of the gas particles is zero.



Picture 4: An example drawing from assignment A1 from group AS 1 with the gas in a container.

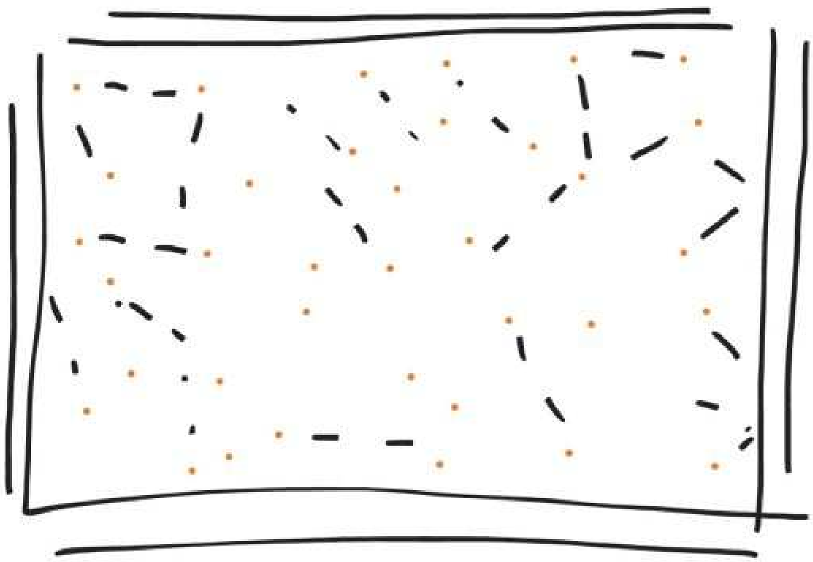
8.2.2 Assignments A2 and A3 for the AS group

Only the AS group completed assignments A2 and A3. They had to look for any differences and similarities between their drawing and the provided one in assignment A2 and then draw a new drawing in assignment A3.

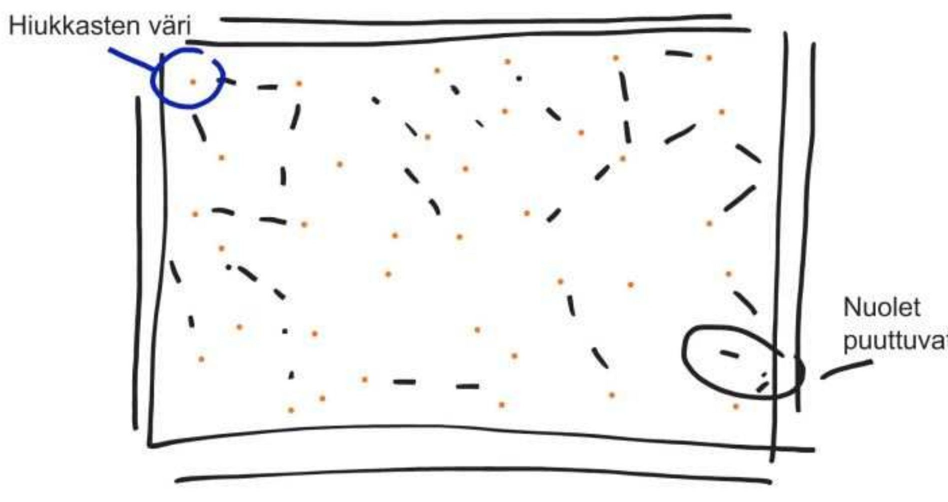
The students did quite well in assignment A2 considering that the drawings in assignment A1 were already quite good. The idea in A2 was not to concentrate on the small details, like colour choices or the size of the gas container. Instead the aim was to direct the students to look for differences and similarities in a larger scale, e.g. if the gas particles collided or didn't move at all. The main difference the students found was that they didn't use arrows to visualize the movement of the gas particles. Arrows were used in the provided illustration. The lack of arrows was pointed out in four of the seven drawings to A2. Two of the seven drawings also pointed out the lack of collisions to the walls of the gas container.

It seems that the comparison between the students' original drawing and the provided one had an effect in assignment A3. Some students drew a drawing in assignment A1 that was imaginative and differed from the traditional type of text books illustrations. After the comparison with the provided drawing, the same students drew a drawing that was very similar with provided, quite traditional drawing. One could even say that the comparison with the provided drawing killed the imagination of the students. This is also noticeable from the students' talk. One pair referred the drawing in assignment A3 as "a copy" of the provided drawing in A2 and another pair said "Ok, I guess we must remember the differences (from A2)".

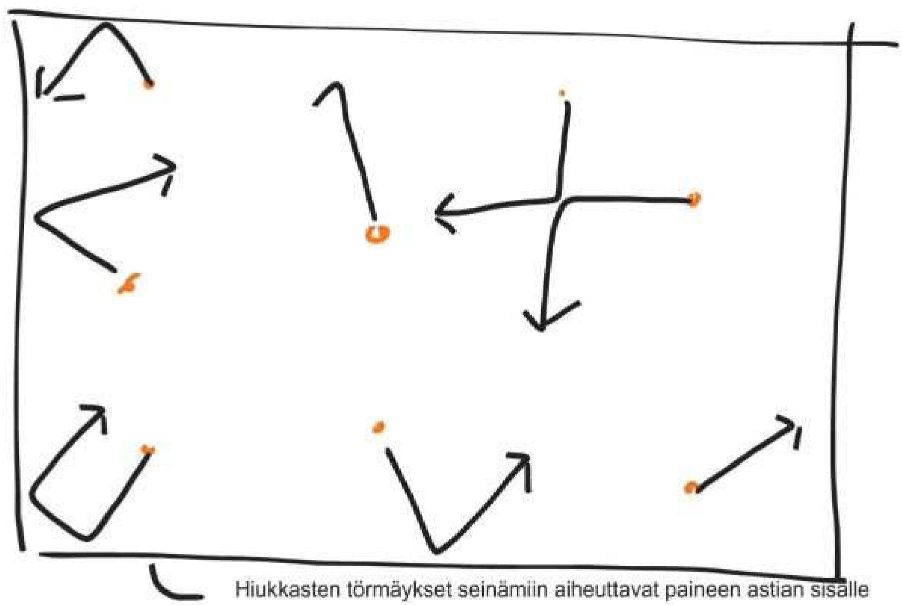
Below is an example of the drawings' change in assignment A1, A2 and A3. The following pictures are from group AS 7 (Picture 5, Picture 6 & Picture 7):



Picture 5: An example drawing to assignment A1 from group AS 7.



Picture 6: An example drawing to assignment A2 from group AS 7. The left upper text reads: “Colour of the particles” and the lower right text reads: “Arrows missing”.



Picture 7: An example drawing to assignment A3 from group AS 7. The text reads: "The particle's collisions with the walls cause pressure inside the container".

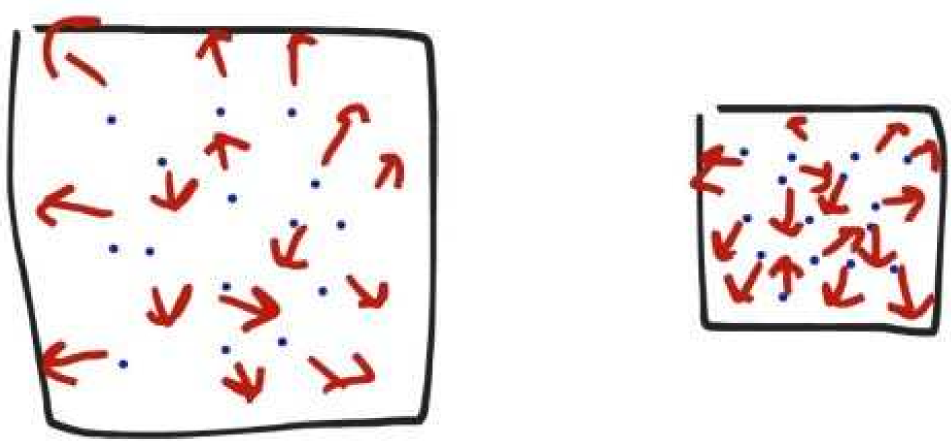
In these drawings we can also see how the representation of pressure changes in assignment A3. The double walls of the container in A1 and A2 are meant to represent the pressure inside the gas container. But in A3 the pair decides to not use their own developed representation of pressure and instead they use particles hitting the walls to represent pressure. This is the same kind of representation of pressure that was used in the provided illustration (see Appendix 1). All of the seven drawings to assignment A3 resembled the provided illustration more than the corresponding drawings from the same groups to assignments A1 and A2. It seems that the students thought that the provided illustration was a "correct one" and that in order to make the best possible drawing they needed to replicate the provided drawing.

8.2.3 Assignment B1

In assignment B1 the students had to represent what happens when the volume of the gas container is reduced while the temperature is held constant. The comparison was to be made to the drawing in assignment A1 (UA group) or A3 (AS group). The students were explicitly told to consider how to represent the changes happening in the system. These changes were the change in volume but also the change in pressure. That presented a problem to the students: how to visually represent something that is everywhere in the gas and is caused by many little collisions?

The most common way of representing pressure was by using arrows to indicate collisions with the container's walls. The use of arrows to show the direction the particle is heading to is a concept familiar from physics text books (see Picture 11 in chapter 9 for an example). The problem that could arise from this is that it is easy to confuse arrows with vectors. When drawing a vector attention must be paid not only to the direction of the vector and to that it is rectilinear but also to its length. If a vector is used to represent a gas particle's velocity, the length of the vector is used to represent the particle's speed. This problem can be seen in Picture 5, where the dash lined arrows are used to imply where the gas particle is heading. The normal arrows are used as vectors to imply the direction and the value of the force exerted to the wall that is caused by the collision with the particle. It seems that most of the students used arrows instead of vectors to represent the gas particle's movement because not much attention was put in the lengths of the arrows. It must be said that some of the students noticed the difference between arrows and vectors. This is discussed in chapter 8.3.

Following is an example of how the group AS 5 represented the rise in pressure as the volume of the gas container is reduced (Picture 8):



Picture 8: An example drawing to assignment B1 from group AS 5 on how to represent the rise in pressure by arrows.

Many of the students used text to complement their drawings[4]. It was used especially to describe the rise in pressure. Six of the eight pairs or groups of three in the UA group used text to that purpose compared to the four out of nine in the AS group. It is possible that examining the provided illustration had an effect on the AS group in this case as well. It may be that they were more reluctant to use text as method of representing pressure because text wasn't used to represent it in the provided illustration.

Two of the pairs, one in the UA group and one in the AS group, used also mathematical equations in their drawings[5]. It is not entirely surprising because equations of state are taught at the same time as the kinetic theory of gases (Hatakka et al., 2005) and pressure is usually taught using the equation presented in chapter 5.1. These two examples show that the students don't have a deep knowledge about equations.

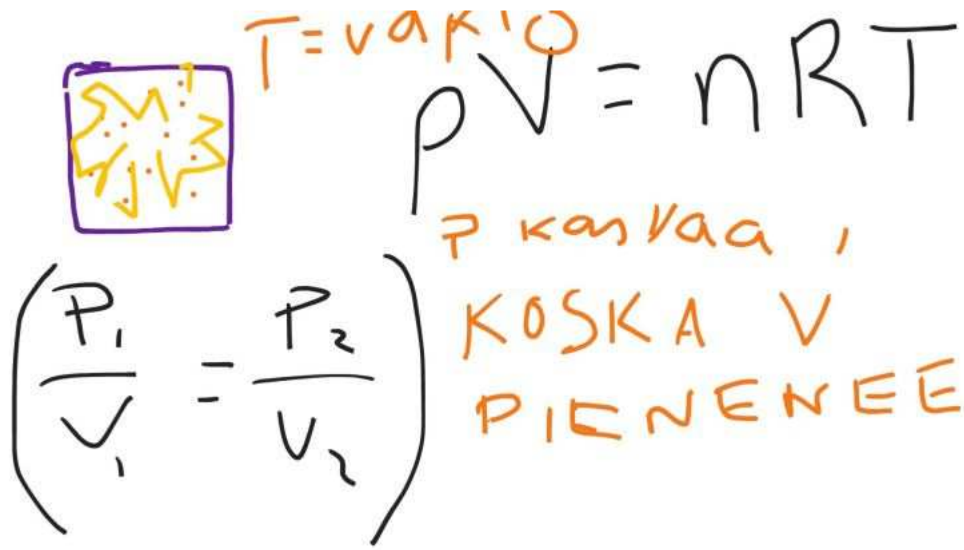
A pair in the UA group decides to include the definition of pressure in their answer but they don't remember it correctly. Instead of $p = F/A$ they put incorrectly $F = p/A$ in their drawing. When the students modify their equation to $p = FA$, they can't understand why the pressure rises even though the surface area of the gas container is reduced as the volume is reduced. They become confused and they end up deleting their equations and sticking with just the drawing.

The previously described drawing was a good example not only of the (improper) use of the mathematical mode of representation but also of the benefits of the tablet computer in gathering data of students' drawings. If this study would have been conducted by pen and paper, the only data for research would have been the final drawings. The tablet computer enables the whole drawing process to be recorded.

[4] These type of drawings belong to the visual mixed -group in Table 2

[5] These also belong to the visual mixed –group in Table 2

Following is the drawing by the second group who used equations in their drawing. It is an example of the incorrect use of the mathematical mode of representation in assignment B1 (Picture 9):



Picture 9: An example of the incorrect use of the mathematical mode of representation in assignment B1 from group AS 6. The upper text reads: "*T* = constant" and the lower text reads: "*p* gets larger because *V* gets smaller".

In the drawing both the Boyle's law of $pV = constant$ and the ideal gas law of $pV = nRT$ are referenced (Hatakka et al., 2005, p.99). Only problem is that the students do not remember the Boyle's law correctly. Their version of the Boyle's law is not consistent with the text that accompanies their drawing. They don't catch their mistake and let the incorrect equation stay in their drawing. The reason to why the students use the ideal gas law correctly could be that it is repeated tens of times in the thermodynamics course. This issue of memorizing equations and the urge to use them in places where they are not needed or are incorrect has been pointed out as an issue in physics education (Van Heuvelen & Zou, 2000).

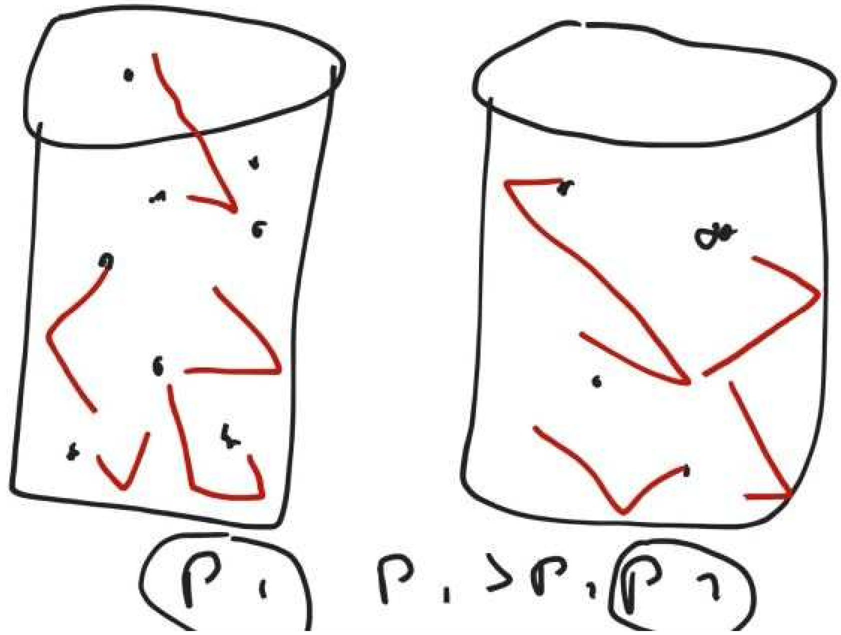
It seems that some students see equations as a useful representation to complement (see chapter 1.1) the drawing. The problem with mathematical equations is that they are very precise and can't be used if not remembered correctly. At least in this study the students' ability to remember the equations correctly was very limited. This issue is discussed further in chapter 9.

8.2.4 Assignment B2

In assignment B2 the students were asked to represent what happens when half of the gas is removed from the gas container. The comparison was to be made to the drawing in assignment A1 (UA group) or A3 (AS group). Here, by mistake, the phrase "as the temperature is held constant" was missing from the study form but the students seemed to assume that the temperature didn't change. This may be because the temperature was explicitly stated to remain constant in assignment B1.

In B2 the most common type of drawing was two containers with one having more particles than the other. There were three of these in the UA group and four in the AS group. The study form informed the students that exactly half of the gas was removed from the container. Only one of the eight drawings from the UA group to B2 contained exactly half the particles as in A1 or in another container. There's a big difference when comparing UA group to the AS group, where six out of nine drawings had exactly half the number of particles. It's unclear why the difference between the groups were so large because the illustration provided for the AS group didn't have explicitly anything to do with the number of the particles.

Some students used one kind of mathematical mode of representation in assignment B2; signs of quantities. Following is an example from the group AS 8 of the use of signs to represent to change in pressure (Picture 10):



Picture 10: An example drawing from group AS 8 of the use of signs to represent the change in pressure. The signs read from left to right: "p_1 $p_1 > p_2$ p_2"

The drawing shows that the students know the conventions of scientific writing with the correct use of footers to indicate different pressures in different containers. It's also a clever way to indicate the rise in pressure without having to resort to plenty of text as seen in e.g. Picture 9. This also keeps the drawing language neutral, because the letters used to represent quantities are the same almost all around the world. This language neutrality is one of the benefits of drawings in education, as discussed in chapter 3.1.

8.3 Analysis of the students' talk

As discussed in chapter 2.4, interpersonal relationships have much to do with collaborative work between students. This was an issue in this study as well. A few of the 17 pairs or groups of three didn't work well together and didn't do much talking. The reasons for this might be that the students didn't know each other well or there might have been some interpersonal issues with the students. This is an issue that can't be avoided when pairs or groups of three are selected randomly and the teacher is not consulted at first. It must be said that most of the students worked well together and there was a positive atmosphere in the classroom.

The use of the three types of talk discussed in chapter 7.2 are analysed separately in the following chapters.

8.3.1 Disputational talk

There was very little disputational talk used in the discussions. Only three of the 17 pairs or groups of three were found to be using disputational talk. Below is an example excerpt of one these disputational talks from group UA 3 (Excerpt 1):

> Student G: *And that's why the [density]-*
> Student H: *[yeah]*
> G: *Rises.*
> H: *Or pressure.*
> G: *Yeah but first [rises] the density.*
> Student I: *[yeah]*
> H: *Yeah well then the pressure-*
> G: *First the density!*

Excerpt 1: An example of disputational talk from group UA 3.

Here the students are disagreeing about whether the density of the gas changes before or after the pressure of the gas. Student G is very determined to express his/her opinion that the density of the gas changes before the pressure but he/she offers no evidence to support that claim. G even yells at student H when H even mentions the term pressure. G doesn't give H the chance to finish his/her sentence but instead cuts it half way through. The conversation feels like unproductive. In cumulative talk the speakers define themselves through their difference with others (Wegerif & Scrimshaw, 1997). This seems to be the case in this excerpt as well.

At least in the Finnish talk culture disputational talk is reserved to only ones closest friends and family. It is considered rude to make decisions in a group without consulting others or without giving reasons for those decisions. At least for teenagers it might be easier to just agree on something than to start arguing. It might also be that the students didn't believe enough in their knowledge on the subject to start an argument. These might be reasons to why there was so little disputational talk observed in the discussions.

8.3.2 Cumulative talk

Most of the students' talk could be categorized as cumulative talk. All of 17 pairs or groups of three were found to be using cumulative talk. ATLAS.ti analysis software was used to find out which topic cumulative talk was most used for. All the topics from all the discussions were coded so the analysis software could be used to find out the most common topics in different talk categories (see Appendix 2).

The topics most discussed using cumulative talk were pressure and the properties, collisions and movements of the gas particles. Because cumulative talk is used when the speakers agree on a subject and there is no need to challenge the ideas of others, it seems that for the most part the students agreed on the cause of pressure and the properties of the gas particles. This is not surprising because the properties of the gas particles and their movement according to the kinetic theory of gases were explicitly given to the students in the study form. The fact that the gas particles' collisions cause the pressure in a gas was also given to the students.

Following is an example of cumulative talk, where three students discuss on the properties of the movement of the gas particles. Cumulative talk is used to improve the cohesion of the group (Wegerif & Scrimshaw, 1997). In this excerpt the group UA 3 from Excerpt 1 seems to work harmoniously and is constructing knowledge by sharing information (Excerpt 2):

Student I: *Ok here's the wall and then these move at a high speed to the wall and bounce away from there… and at the same time also collide with each other where they bounce into different directions.*
Student G: *And their movement is always rectilinear.*
Student H: *It [sure is].*
I: *[Yes].*
H: *And fast.*
G: *And random.*

Excerpt 2: An example of cumulative talk UA 3.

The students complete each other's sentences and confirm the statements of the other speakers. These are some of the identifiers of cumulative talk (Mercer, 2004). There seems to be a lack of deep knowledge about the subject. The students just recite the three properties for the movement of the gas particles without stopping to think about them.

Other places where cumulative talk was used was when the AS group compared their drawings to the provided illustration in assignment A2. It seems that the students agreed in the differences and the similarities found. Following is an excerpt from a discussion from group AS 7 where cumulative talk is associated with comparing the drawings (Exceprt 3):

Student J: *Maybe those arrows are different.*
Student K: *Yeah maybe that doesn't show from where and to where maybe.*
J: *That's right.*
K: *So that could have been.*
J: *So (reads out loud) mark them in your original well yeah so maybe we could circle something from there… these dash lines.*
K: *Yeah*
J: *Like so… and then what other differences those colours at least… could be one.*
K: *Mmmm*
J: *So the colour of the particles*

Excerpt 3: An example of cumulative talk in assignment A2 from group AS 7.

In the excerpt the students agree that they are missing the arrows that show where the gas particles are heading to. This was the most common difference between the students' drawings and the provided illustration as discussed in chapter 8.2.2. The students also agree that the colours of the particles are different than in the provided illustration.

This excerpt also shows one of the key aspects found in cumulative talks in this study; one person leads the conversation and the other mainly follows and agrees with him/her. It was common in the conversations to one student to take the commanding role and the other student is left with a lesser role. This may reflect the social situation among the students. It's easy to agree with the person in the group who seems to lead the discussion and is most vocal in voicing his/her opinion.

8.3.3 Exploratory talk

In the study, seven of 17 pairs or groups of three were found to be using exploratory talk in their discussions. Only one of these three pairs or groups of three used also disputational talk. There was more exploratory talk than disputational talk but much less than cumulative talk. The most common use of exploratory talk was when the students had a problem or were unsure how to continue (see Appendix 2). It seems natural that these kinds of situations would give an opportunity to open up the discussion for fresh ideas. When the method of action or drawing style is not obvious, the help of the other group members is needed. It isn't always easy to express one's lack of knowledge about something that might explain the lack of use of exploratory talk.

Following is an excerpt from a discussion from group UA 8 where two students have a problem concerning the different methods of representing pressure and temperature in the gas container (Excerpt 4):

Student L: *We should find a way to represent the pressure and the temperature there.*
Student M: *Well maybe in a smaller container if we drew a smaller container then that would have a higher pressure.*
L: *Mmm how do we draw that?*
M: *Well it doesn't have to- it's smaller and it has like more particles in it [or] the same amount of particles but it's just smaller. Should I draw a smaller container here?*
L:
[yes]
M: *You can draw the particles again, draw it full of those particles… how did the pressure affect this case?*

Excerpt 4: An example of exploratory talk from group UA 8.

In this excerpt student L asks a question from student M: "How do we draw that?" L wants M to share information and to give ideas on how to represent pressure and temperature. M gives his/her opinion and L agrees. Ultimately M himself/herself is not sure how the pressure affects the case and asks for L's opinion. The question remains unanswered but they both open up their thinking to new ideas and are willing to hear other opinions. These are some of the identifiers of exploratory talk (Mercer, 2004).

Following is another excerpt from group UA 2 in which the students come across a phenomenon that is not easy to draw and the discussion is opened up for fresh ideas (Excerpt 5):

Student N: *And well then we could draw their movement there… well take the red colour so it shows.*
Student O: *So they're (inarticulate) polygonal chains.*
N: *Yeah polygonal chains for them… that some of them move faster and some slower I don't know how we could put it there but.*
O: *Well what if we use those vector things…*
N: *Yeah.*

Excerpt 5: An example of exploratory talk from group UA 2.

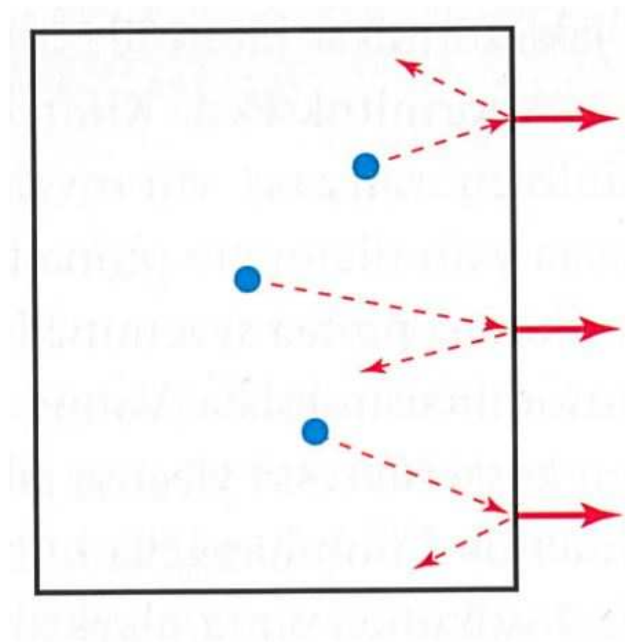
Student N has problems on figuring out how to express the velocities of the particles. He/she openly admits that he/she has a problem. It offers student O the chance to express his/hers idea that vectors could be used to express the velocities. Student N sees this as a good idea and agrees to it.

9. Discussion

The first research question was about how upper secondary school students use drawings as a tool for meaning-making in physics. This study didn't study learners' individual meaning-making processes but focused on the cooperative meaning-making. The students had to co-operate in trying to choose how to represent the phenomenon. Sometimes there were difficulties in finding the mutually accepted type of representation. This dialogic process forced the students to process their own internal models about the phenomenon and to choose the best possible visual or textual representation. Drawing was a way of transferring information between the students. The dialogic process also forced the students to verbalize and/or visualize their internal models into external models. The talk of the students and the drawings served the same purpose; to serve as a psychological tool for conveying and processing information. Some phenomena, such as the perpendicular motion of particles, are best suited to be represented visually. Other phenomena, such as pressure, are perhaps best represented verbally. These preferred representations can differ between different students. All in all it seems that the students used drawing efficiently as a tool for conveying and processing information.

The subject of learner-generated drawings is an interesting one, especially on science education. Much of the information in science is conveying through the visual mode, which encompasses both graphs and drawings. The Finnish national curriculum for physics and for upper secondary schools states that one goal of physics education in upper secondary schools is that the students learn how to represent data in graphical form (Finnish National Board of Education, 2003, p.149). The subject of learning how to represent information in other types of visual representations is not mentioned in the curriculum. The students examine the drawings in their text books but they aren't given the chance to produce similar visual representations that can be imaginative but still informative. The same amount attention is not paid to scientific drawing skills as is to scientific writing skills. Teachers often lack the knowledge in how to aid the students in their drawing process (Scott & Jewitt, 2003). Drawing could aid students who have e.g. learning disabilities or language difficulties. They are a more physical representation that can help students to process information (Ogborn et al., 1996).

It was also apparent that most of the groups were familiar with the canonical way of expressing the movement of the particles in an ideal gas. This type of drawing is used in some upper secondary school text books. Below is an example of these kinds of illustrations (Hatakka et al., 2005, p.66) (Picture 11):



Picture 11: An example illustration from the text book used by the students in their thermodynamics course (Hatakka et al., 2005, p.66)**.**

This picture also highlights one of the problems with using drawings as a representation: they can be easily misunderstood. The dash lined arrows represent the movement of the particles and the other arrows represent the force exerted on the wall by the collisions between the particle and the wall. One has to have some background knowledge about drawing conventions in physics to “get” the picture. Some of the groups managed to produce drawings that were imaginative and differed from the conventions. Especially when visualising pressure the groups had to use their imagination to represent something that is difficult to represent visually. Guiding the learning with drawing for these students who “think outside the box” is a challenge to the teacher.

The second research question was if guidance had an influence in the students’ drawings’. The statistical analysis discussed in chapter 8.1 shows that there was no statistical difference between the UA and AS groups in assignment A1 which was similar for both groups. This implies that there was no major difference between the groups' previous knowledge and drawing abilities. In assignments B1 and B2 the difference between the AS group and UA group was statistically significant, with the AS group including more of the criteria deemed important in the kinetic theory of gases. This doesn't mean that the AS group has a deeper knowledge on the subject than the UA group. This study only tested the students' ability to produce a drawing about the phenomenon. If the students had been tested with e.g. a questionnaire, the results could have been different. Because the group sizes were low, one can't draw any conclusions about the superiority of guidance in drawing from this. These results are not to be generalized. What can be said is that guidance helped the students in this study to draw more of the important aspects of the kinetic theory of gases. This falls in line with the generative theory of drawing construction discussed in chapter 3.2. Because the students in the AS group had seen a visual representation about the different aspects of the subject, they had imagens or visual representations to activate when needed. The UA group had to develop visual representations based on their internal verbal representations about the different aspects of the subject at hand.

The guidance in the form of comparison with the provided drawing altered the drawings by the AS group to be more in line with the traditional text book drawing. This can be seen as a slight drawback in using comparison as a method of guidance. While the method doesn't explicitly require the students to change their drawing style, it seems to affect it. The style of the provided drawing is taken to be the correct one and it is then reproduced in the students' own drawings'. All in all the data confirms the research hypothesis discussed in chapter 6. Other methods for guidance in drawing were not studied in this thesis. It would be interesting to compare other guidance methods with the one used in this thesis.

Two groups used equations as a part of their drawings. It is sad to notice that both of these groups used them incorrectly. They didn't remember the correct form of the equation. Students may use certain of equations with certain problem types (Sherin, 2001). In this case, the students might have associated problems dealing with a gas and its properties to the ideal gas law and the other laws of state. Students often lack the understanding about the science behind the equation. Another possibility is that they don’t connect the phenomena on which the equation is based to the mathematical representation of it. In both cases the students would have been able to correct their errors with a little reflection and thinking. Students’ ability to use and modify equations is an interesting research subject.

The third research question was about what kind of talk upper secondary school students use when they are engaged in a meaning-making process. In this study the talk was mostly cumulative. This type of talk is not as productive as exploratory talk, but it is also not as uncooperative as disputational talk. Students didn’t make much effort in order to try to engage in critical talk and in high-level construction of shared knowledge. The atmosphere in the talks was supportive but other group members’ ideas’ were not critically thought over and alternative ideas were not presented. Studies have shown that the talk younger children use when they are working together is often uncooperative and unproductive (Arvaja, 2005; Galton & Williamson, 1992; Wegerif & Scrimshaw, 1997). The quite low quality of talk observed confirms the research hypothesis discussed in chapter 6. The quality of the talk could improve if e.g. the students’ teacher is consulted when dividing the students into pairs or groups. It would also be interesting to see if letting the students choose their own pairs or groups would have an effect on the talk.

The fact that the students’ had already been taught about the kinetic theory of gases may also have affected the quality of the talks. Because all of the students had been on the same thermodynamics courses a year earlier, they had also received the same kind of teaching. This could have led to them having somewhat similar internal models about the subjects. When the internal models are similar, there is no need for critique and alternative ideas. There is still need for study about students’ talk in other situations e.g. how does talk and drawing connect with each other when the students have to draw their conception about something that they have just learned.

The final research question was about the possibilities that using a tablet computer can bring to education research. The device is well suited for recording the drawing process and the students’ talk. It enables the researcher to simultaneously capture the drawing process and the talk associated with the process without having to combine the two afterwards. The device’s microphone also captures speech well even in a room with other students talking. Today's upper secondary school students are also used to working with tablet computers. The students in this study didn't have any difficulties with operating the device. With a different study group this could become an issue. The Educreations application used in the study was not designed to be used for research purposes. The applications drawing tools were limited. It meant that the students couldn't draw exactly what they wanted because the application didn't allow e.g. different line widths. Handing out special drawing pens which could be used with the tablets could also ease the drawing process. All in all although the application was meant for a different use, it served fine as a research application. It would be interesting to study the use of an application such the Educreations as a tool to produce online lectures and the learning results of using such lectures.

If tablet computers were to be used more seriously in this kind of research, the best option would be to code a special application for the purpose. This specially coded application could also serve as an interdisciplinary project between experts of information technology and education. It also could mean that the data coming from the application would go directly to the researcher and not any third parties. The application could have better drawing tools and it could also enable the tablet computers front camera to be used to record the students working with the device. This could bring more information about the information sharing that is going on between the students. Gestures are also a mode of representation that is used to convey information. In this study that information was lost because the students' gestures were not recorded. Often the students also pointed at something on the tablet computers screen to emphasise that they were talking about that particular object. Recording the students' movements could also help with interpreting the students' talk.

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Appendix 1: The study form for the AS group

PART A

You and your partner get to read a short text. A drawing assignment follows that text. You must use the information from the text in the assignment. You can read the text as many times as you want and you can also read the text during the assignment.

All groups don't have the same assignments, but the text is the same to all the groups.

Using the program:

You can undo your last drawing from the arrow at the top bar pointing to the left. From the T-letter in the top bar you can add text to wherever you want in the drawing. You can change the colour from the left side of the top bar. You can have four colours at once in the preset buttons.

You can change pages from the arrows in the lower bar, from the lower right corner you change to the next page and from the lower left corner you can change to the previous page. **You must change pages whenever you have a new assignment.**

Remember:

Make sure that **the recording is on** (it says **REC** in the top right corner) **ALWAYS** when you are drawing something on the tablets.

NB! When you are drawing something with the tablet, the recording goes off. Make sure to remember to **put the recording back on** when you have written your text.

The tablets also record your conversations and they will also be used in the study. **It is important that you talk about your opinions and thoughts!**

The Kinetic Theory of Gases

The kinetic theory of gases aims to explain the macroscopic properties (things you can observe) of gases (e.g. pressure, temperature and volume) with the motion of the microscopic particles (things you can't observe) of the gases. The random motion of these particles is called **thermal motion**. It's becomes faster as the temperature of the gas becomes higher.

The kinetic theory of gases is closely linked with the concept of an **ideal gas.** It is assumed that an ideal gas consists of a large number of point-like particles which move randomly. The **pressure** of the gas is caused by the net force from the collisions these particles have with the walls of the gas container.

The basic postulates or basic assumptions of the kinetic theory of gases are e.g. as follows:

1. The gas consists of identical point-like particles. Their volume is zero.
2. The particles are in a constant random motion, which is fast and rectilinear.
3. The particles collide with each other and with the walls of the gas container. Because of that the trajectories of the particles are polygonal chains.

(Retold from Physica 2: Lämpö and Fysiikka 2: Lämpö – text books)

TURN THE PAGE ONLY AFTER YOU HAVE READ THE TEXT PROPERLY!

Assignment A1:

Draw a drawing in which you represent an ideal gas as good as you can in accordance with the kinetic theory of gases.

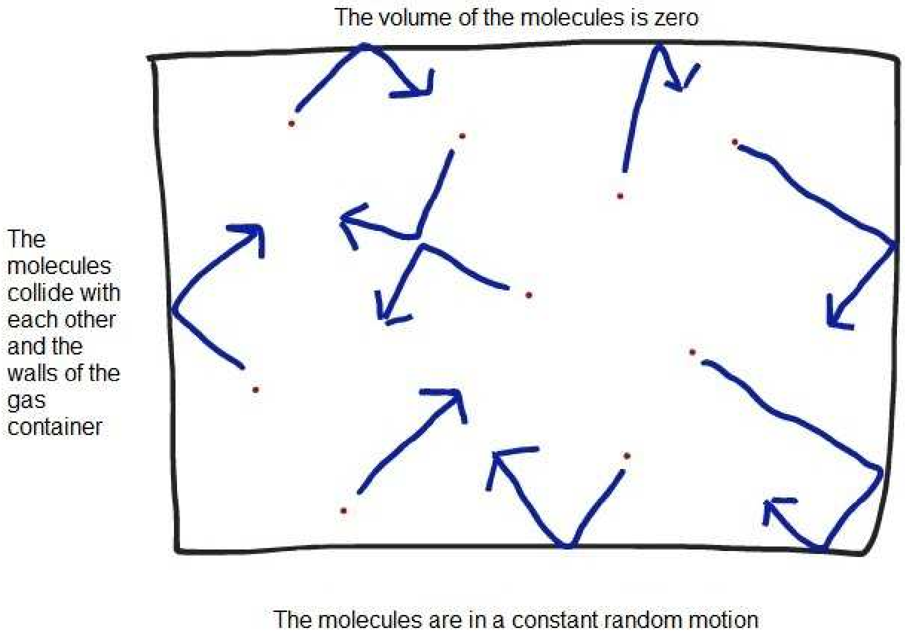
Your **drawing** can also contain text. Use different colours if necessary.

Draw the **drawing** in **collaboration.**

It is important that you **talk** as much as you can about why you are drawing just the thing you are drawing. You can e.g. ponder different choices out loud and think about what elements your **drawing** should have.

Try to talk in a way that the tablet's microphone can record your conversations. The tablet records both your conversations and your drawings'.

TURN THE PAGE ONLY AFTER YOU HAVE COMPLETED YOUR DRAWING!



Assignment A2: Compare the drawing above with your drawing about the same subject.

Mark the differences between the drawing above and your drawing by e.g. circling them in your original drawing. Don't get caught up with small details, like the exact number of particles or the exact colours. Try to focus on the matters that are essential considering the subject you are learning about.

Talk about the differences you found while you work, do you agree on the differences?

TURN THE PAGE ONLY AFTER YOU ARE FINISHED COMPARING THE DRAWINGS!

Assignment A3:

Turn to a new page in the program.

Now draw a new drawing in which you represent an ideal gas as good as you can in accordance with the kinetic theory of gases.

Your drawing can also contain text. Use different colours if necessary.

Try to talk in a way that the tablet's microphone can record your conversations. The tablet records both your conversations and your drawings'.

TURN THE PAGE ONLY AFTER YOU HAVE COMPLETED YOUR DRAWING!

PART B

You will read another short text. Few assginments will follow this text. The same rules apply, you can read the text more than once and you may also read the text during drawing.

The equations of state for gases

The different equations of state for gases can be explained using the kinetic theory of gases:

- If the temperature of the gas is held constant and the volume of the gas is reduced, the average mean speed of the gas particles doesn't change, but the particles are packed closer together. As the density of the gas increases the collisions between the particles and the walls of the gas container get more frequent. This increases the force applied to the walls by the collisions and that increases the pressure of the gas.

- If the volume of the gas is held constant and the temperature of the gas is increased, the average mean speed of the gas particles is increased. Now the collisions between the gas particles and the walls of the gas container get more frequent and they are more energetic. That causes the force applied to the walls to increase and that increases the pressure of the gas.

- If the pressure of the gas is held constant and the gas is heated, the average mean speed of the gas particles is increased. Now the collisions between the gas particles and the walls of the gas container get more frequent and they are more energetic. That would increase the pressure of the gas. In order to the pressure of the gas to stay constant, the gas container's and also the gas's volume must increase.

(Retold from Physica 2: Lämpö - textbook)

TURN THE PAGE ONLY AFTER YOU HAVE READ THE TEXT PROPERLY!

Assignment B1:

Turn to a new page in the program.

Assume the drawing which you drew after the comparison as the starting point. In that drawing you represented an ideal gas in accordance with kinetic theory of gases.

Now draw a new drawing in which you represent what happens **when the volume of the gas container is reduced while the temperature is held constant.**

Consider how you represent the changes happening in the system.

Your drawing can also contain text. Use different colours if necessary.

Try to talk in a way that the tablet's microphone can record your **conversations**.

TURN THE PAGE ONLY AFTER YOU HAVE COMPLETED YOUR DRAWING!

Assignment B2:

Turn to a new page in the program.

Assume the drawing which you drew after the comparison as the starting point. In that drawing you represented an ideal gas in accordance with kinetic theory of gases.

Now draw a new drawing in which you represent what happens **when half of the gas is removed from the gas container.**

Consider how you represent the changes happening in the system.

Your drawing can also contain text. Use different colours if necessary.

Try to talk in a way that the tablet's microphone can record your **conversations**.

TURN THE PAGE ONLY AFTER YOU HAVE COMPLETED YOUR DRAWING!

Thank you, the study is now completed!

Stop the recording and wait for further instructions.

The most important thing is not to do anything that would cause the drawings to disappear!

Appendix 2: Co-occurrences of codes and talk types

	Disputational talk	Cumulative talk	Exploratory talk
Pressure	0.02	0.22	0.04
Collision	0.01	0.21	0.02
Particle	0	0.21	0
Volume of particles	0	0.2	0.01
Collision to the wall	0	0.17	0.01
Gas container	0	0.16	0.04
Collision between particles	0.02	0.14	0
Volume of particles is zero	0	0.13	0
Point like	0	0.1	0
Amount of substance	0.02	0.09	0
Identical particles	0	0.08	0
Rectilinear motion	0	0.08	0
Arrows	0.03	0.07	0.02
Random motion	0	0.07	0
Velocity of particles	0.03	0.06	0.09
Temperature	0.02	0.06	0.07
Movement of particles	0	0.06	0.04
Constant motion	0	0.05	0
Similarity between two drawings	0	0.05	0
Elastic collision	0.11	0.03	0
Fast motion	0	0.03	0
Non-point like	0	0.03	0
Problem	0.09	0.02	0.25
The number is the c-coefficient calculated by the equation c := n12/(n1 + n2) – n12. (n12 = co-occurrence frequency of two codes c1 and c2, n1 and n2 being their occurrence frequency).			