Bringing Principles to Rigging for Animation

Teaching rigging within game development education

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Abstract

The subject of digital animation witnessed the indispensable role of rigging in enabling movement and functionality, particularly within the context of game development. While animation principles (Thomas & Johnston, 1995) form the foundation of this discipline, rigging principles remain somewhat elusive, lacking the same fundamental status even to this day. As a highly technical subject, rigging can pose challenges to students who may not be aware of its intricate logic, yet still have to contend with it. This study presents an epistemic solution designed to elucidate the logic of rigging by emphasizing fundamental concepts over ready-made solutions. A full list of concepts was defined. To evaluate the effectiveness of this pedagogical approach, a workshop was held, focusing on experiential (Kolb, 2014), concept-based, teaching. It was compared with a control group whose workshop inherited the traditional pedagogical methodology. Afterwards, both groups were handed a convergent and a divergent test assignment (Guilford, 1968). Qualitative data was gathered through interviews, capturing student's reflections and opinions on the respective workshops and test assignments. Results show a positive attitude towards both teaching methods. However, there was a particular alacrity among the students in the concept workshop, and they appreciated its pedagogical differences. Some students appeared to pick up on the epistemology and even expressed a realization of "why", and in doing so, stated the epistemic goal verbatim. Moreover, the traditional methodology entails less engagement in the convergent test assignment, further proving the potential for creative thinking (Runco, 2014) in the procedural test assignment. This demonstrated the potential benefit of this approach to education. This study is meant to start a discourse on effective pedagogical strategies in the context of rigging for digital animation, shedding light on the benefits of concept-based teaching. With more resources, it would have also focused on how the concepts affect game development directly.

Keywords: Rigging, Animation, Teaching, Pedagogy, Math anxiety.
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1 Introduction

I often come across this issue when I teach rigging to my students. In the digital arts, new game art students are often appalled when faced with rigging for the first time. Fascinated with the intricacy achieved by its functions, but at the same time scared by the overwhelming amount of new information presented to them. Looking at an advanced rig can promise a reaction of marvel. However, as soon as they take a closer look at the basics—the techniques used to create the rig—more often than not, distaste is put forward. Generally speaking, everyone likes to see the finished product, but when looking at the breakdown, it is sometimes difficult for them to understand the implication: how the concepts of rigging correspond to the finished product.

Some might state the role of rigging in the form of a rhetorical antithesis. Claiming that rigging is not a small part of animation, but animation is a small part of rigging. Well, it depends on perspective, and even the case, I would argue. Nevertheless, when rigging is just a small part of the animator’s work, it still plays a big role in the process of animating. Rigging can limit what is possible, and enable what was thought to be not. It is safe to say that animation, in the digital age, is dependent on rigging.

In video games, animation is both an artistic and technical challenge (Cooper, 2021). The artistic part of the challenge is to make the object (or character) move in an appealing way. And the technical part is prescribed as rigging. The role of rigging is hard to define and even more difficult to put into simple words. The rig's role, however, can be stated as the literal skeleton of the movement. Meaning rigging, as a verb, is to design and to create this skeleton. To animate is to choreograph movement for the skeleton. Animation is found in many contexts of digital art. Yet, in game development, rigging is even central to the functionality of the animated object in the game. Meaning that rigging expands all the way to the rims of game-functionality.

In game development, roles tend to vary in general, with some even hard to define (Karlsson et al., 2022). Rigging is no exception. Depending on the size of the team developing the game, the role of the animator can look very different. In large teams, the animator can be specialized and focus solely on animating the movements. Rigging thus becomes its own profession. In smaller teams, on the other hand, the animator is often expected to handle both (Cooper, 2021).

This work should be considered a foundation for future works. The goal is rigging for games. However, this study examines just the first steps of the journey to the game engine. It is compatible with rigging in game development, whilst still being intelligible for any application of rigging. This means that its role is not explicit. After all, games as a medium provide more possibilities and limitations to follow.
2 Background

The background covers areas of research relevant to the study. The problem is also aided by a background on a few different pedagogical methods and prejudices. Finally, the results of a survey are presented, meant to reveal the thoughts and reflections of students.

2.1 Math Anxiety

In educational settings, individuals may suffer from test and performance anxiety that are connected to a knowledge domain. The most prominent one is math (Luttenberger, Wimmer & Paechter, 2018). Mathematics-anxious students are likely to become mathematics-avoiders. Consequently, they cannot fully participate in today’s technological society (Hutter, 1995). It has been acknowledged that math anxiety poses a severe problem over entire life spans (Luttenberger et al., 2018). Most studies on math anxiety have drawn their conclusions based on high school and college students (Hutter, 1995).

Not only conventional arithmetic and math problems trigger the math-anxiety reaction. It is enough that the task requires a counting-like process (Ashcraft & Kirk, 2001), see Logan and Klapp’s (1991) alphabet arithmetic task. In the study of Ashcraft and Kirk, the most important new finding was that working memory capacity was negatively associated with math anxiety (Ashcraft & Kirk, 2001). Working memory is the theory of a cognitive system that provides temporary storage and manipulation of the needed information for complex cognitive tasks. This cognitive system requires simultaneous storage and processing of the information (Baddeley, 1992). Individuals are particularly impaired if a task requires working memory and they are already devoting some of their working memory's capacity to the on-line anxiety reaction (Ashcraft & Kirk, 2001).

On-line cognition refers to the process of live tasks that require fast moment-by-moment processing: eating toast, for example. Off-line cognition, on the other hand, is used to check on something odd or plan future behaviour, like suddenly realizing that the toast has been finished and there is no more left to eat. This breaks continuation of the on-line cognition (Harris, 2018).

It is important to consider math anxiety when trying to increase math achievement (Foley et al., 2017). Mathematics teachers must do what they can to prevent mathematics anxiety (Hutter, 1995). Experts in the fields of education and mathematics, along with sufferers of mathematics anxiety, have offered their suggestions for alleviating math anxiety. Yet, few of these prescribed strategies have been adequately tested (Hutter, 1995). Moreover, findings indicated that field dependent learners experienced more mathematics anxiety than did field independent learners (Hadfield & Maddux, 1988).
Math anxiety should not be confused with stress. Math anxiety has a bidirectional relation to math performance with a negative effect. This can even be observed as a cross-national phenomenon—with a falling trend line (Foley et al., 2017). Put in simple terms: the higher the math anxiety, the lower the math performance. Or contrariwise: the lower the math performance, the higher the math anxiety.

2.2 Stress

Stress can be both good and bad for performance, depending on the strength of stimuli. This notion was conceived as early as in the discrimination experiments of Yerkes & Dodson (1908), now called the “Yerkes–Dodson law”. The theory states that the relation between stress and efficiency of learning is curvilinear—worst when stress levels are very weak or very strong, and best at various intermediate levels (Yerkes & Dodson, 1908 in Mandler, 1989). This suggests that the optimal level of stress is not a non-existent level of stress. For example, stress can help filter out irrelevancies during a problem-solving task (Mandler, 1989). However, it may also result in focusing on the wrong strategy, as “…inadequate information leads to stress, but the well-informed individual can use stress constructively.” (Mandler, 1989, 10).

Emotions, just like stress, are a response to stimulus. Stress can be associated with emotions because stress triggers emotions. Emotions are both psychological and physiological. However, fundamental emotion theorists cannot agree on how many or which the basic emotions are (Mandler, 1989). Cognitive theory prior to the end of the twentieth century would lead you to believe that human beings are unable to feel. People were described as “…passionless creatures who think and act rationally and coolly.” (Mandler, 1989, 4). This was most obvious in the investigation of problem solving. However, human beings typically feel an array of emotions, such as anger, joy, frustration and pleasure when dealing with complex problems. If the goal is to form a true understanding of human thought and actions, research must also consider the emotional aspects (Mandler 1989).

2.3 Creativity

Creativity as a subject has long been neglected in the area of psychology (Hutchinson, 1931 & Guilford, 1950). Guilford coined the term Divergent thinking to describe the process of generating original ideas and new possibilities. Divergent thinking is the generation of a variety of ideas and alternative solutions to problems (Guilford, 1968). It is employed when faced with an open-ended task, like “How can a brick be used?”. From this perspective, divergent thinking is a kind of problem solving (Runco, 2014). Because some of the resulting ideas are original, divergent thinking also represents the potential for creative thinking (Runco, 2011). Divergent thinking lies in contrast to convergent thinking (Guilford, 1968). In convergent thinking, one answer is correct (or conventional), like “Who won the
1988 World Series?" (Runco, 2014). Guilford’s methods have been questioned, yet much of his thinking on creativity was, and remains, remarkably influential. Particularly his conception of divergent and convergent thinking (Albert & Runco, 1999).

If creativity is the process of making something new and useful, it is difficult to measure in a traditional sense—as a personal ability. Attempts to measure it have been variable in both method and results. Tests such as the Torrance Tests of Creative Thinking have issued that creative individuals usually have the ability to discern a variety of solutions to a single problem (Torrance, 1974). Moreover, in this test, fluency describes the number of appropriate solutions relevant to a specific task or problem (Torrance, 1974). However, as Guilford argues, creativity (and creative productivity) extend well beyond the domain of intelligence. What is more, creativity might also vary depending on where you find it (Guilford, 1950).

### 2.4 Method for learning

The first question in teaching is of course what to teach; what content to show and in what order. Furthermore, another question is how to teach it; how to present or instruct it. With variance from this, theories about learning suggest that you should not even focus on a method for teaching, instead, you should start by focusing on a method for learning.

#### 2.4.1 Experiential learning

In such an abstract area as rigging, it can be difficult to form an understanding about the concepts because there is no frame of reference. In such an environment, making it relatable and engaging should be a priority. Through the practice of experiential learning a given concept could be made more tangible for students. Experiential learning is learning through reflection on doing. Here, the experience comes first, it is the foundation for learning (Kolb, 2014). It is:

> “Learning in which the learner is directly in touch with the realities being studied. It is contrasted with learning in which the learner only reads about, hears about, talks about, or writes about these realities but never comes into contact with them as part of the learning process.”

(Keeton and Tate, 1978, in Cell, 1984: viii).

Oftentimes, a course about practical subjects gives the learner the experience of working with the subjects. The learner can then build upon this experience after the course is over. The point is to put the learner through as many scenarios as possible, prepare them for as many situations as possible. For rigging, this can be to rig arms, legs, torso, shoulders, etc. Meaning, a lot of different body-parts. One might think that this is in line with experiential learning. The learner is in fact participating in the methods by using them. However, despite what the name might suggest, experiential learning advocates that reflection on
doing is the main point (Kolb, 2014). Hence, without promoting reflection, it becomes just conventional hands-on learning. Accordingly, reflection should really be highlighted and accommodated in the course as an important part of the process for learning. From this standpoint, the traditional method is incomplete, or at least ineffective. The method depends on the student's own motivation to reflect on everything after the fact. Ineffectiveness comes from an imbalance between observation and action (Kolb, 2015). So, according to experiential learning, if you are able to compress the learning experience to conclude both experience and reflection within the frames of the course, that is better.

Experiential learning has already been elevated in a case very similar to rigging concepts (see, Elyan 2012). The study in question applied experiential learning to improve students' understanding and appreciation of mathematical concepts: B-Splines, Bezier Curves, Free Form Deformation (i.e. not linear deformation, nevertheless deformation of vertices). In the study, student's engagement was encouraged by first giving the students experience of some practical implications of the concepts. In reality, this meant that the concepts were first introduced in the form of practical hands-on experiments using a software tool that exercised the concept in question. The students utilized their technical skills—their familiarity with the software being used—to better understand the concepts. As such, the software acted as an intermediator, a space where the students were already familiar. As the study finds, this helped the students to understand the concepts. It was found that some of the concepts can be introduced in this way, and when they did, it resulted in students performing better in coursework and also in positive feedback overall. To explain the procedure in short, in the study, they gave students simple, short and closely related practical activities with a given concept before the concept is discussed in class. This is in-line with experiential learning. However, in the article, formally, the framework was constructed based on Activity Led Learning and Problem Based Learning. Similar to an action-based approach (Elyan, 2012).

An Action-based approach puts human agency at the center of attention. The agency, rather than the particular curricular organization, is the defining construct. This means that students play an active role in the way of their own education. In practical terms, they must have things to say to each other and to the teacher that go beyond the edict given by the textbook (Lier 2007). This is unlike traditional methods in a learning environment, where students sit in rows or chairs facing the front like they have for centuries and the teacher hands them information. And they are then to focus on the instructional materials and through memorizing information, and practice to gain fluent skills (Lier 2007). This is something that experiential learning coincides with. The focus is active and continuous learning, rather than scoring on a test. “Learning is Best Conceived as a Process, Not in Terms of Outcomes.” (Kolb, 2015, p.26).

2.4.2 Technology-enhanced learning

The use of digital software when learning is often defined as e-learning; however, it is actually a sub-part of “digital learning” (Mehdipour & Zerehkafi, 2013). Furthermore, e-learning means different things in different contexts, it even means different things in different sectors. It has evolved in different ways in the education, business, military, and
training sector (Nicholson, 2007). There have also been disagreements about what it covers. For example, if the range of content is delivered via CD’s, the Internet, audio- and video recordings, broadcasts, or interactive TV (Moore et al., 2011). In the “school sector”, it covers both online and software-based learning. Yet, in higher education it refers solely to a range of on-line practices (Campbell, 2004, in Nicholson, 2007). E-learning is often regarded as a new form of learning that uses the affordances of the Internet. However, this view fails to recognize its extensive connections to pedagogical theories that have shaped the use of e-learning (Nicholson, 2007). Because of this, it has led to simultaneous development of different notions, foci and labels for technology-enhanced learning (TEL) (Nicholson, 2007). In education, it is often taken for granted that technologies can “enhance learning” and the term TEL is increasingly being used to describe it (Kirkwood & Price, 2014). Overall, e-learning has been used with a confusing variety of meanings. It can now be said TEL subsumes the older term “e-Learning”—referring to the application of information and communication technologies (Guri-Rosenblit & Gros 2011).

Nowadays, mobile learning (m-learning) products and services are easily accessible in the form of apps. In its journey to popularity, however, things used to look different. Nevertheless, m-learning “…is certainly not merely the conjunction of ‘mobile’ and ‘learning’; it has always implicitly meant ‘mobile E-Learning’ and its history and development have to be understood as both a continuation of ‘conventional’ E-Learning and to its perceived inadequacies and limitations.” (Mehdipour & Zerehkafi, 2013, 93). There are now many apps on the market intended for learning, with a wide range of content. However, as one study points out, it is unclear what deems an app worthy of the title “educational” on today’s app stores (Griffith et al., 2020).

When searching the internet today, the only prominent method for learning rigging is through online videos. However, these are not interactive, and therefore fail to provide the learner with agency in their method for learning. Nor is it a cadre of reflection, necessary for experiential learning. Nevertheless, it is one of the most convenient ways for learning rigging—wherever you are. This is in accordance with mobile learning.

### 2.4.3 Self-regulated learning

Being self-taught is often celebrated amongst students—to have made it by yourself. Self-learning is achieved when the learner makes the effort to identify their own learning goals and needs, and collect resources themselves. However, simply formulating methods toward attaining their personal goals does not necessarily imply being self-taught. The act of formulating this method can be crucial in any learning situation. When the learner is proactive and personally formulates a plan of action toward personal goals, it is considered a self-regulated form of learning (Zimmerman & Schunk, 2011). So, self-regulated learning is not an individualized form of learning, because it also includes conventional methods for learning, such as seeking help from teachers or peers (Zimmerman & Schunk, 2011). Meaning the self-regulated learner makes sure to verify their methods, and this infers using methods not exclusive to autodidactic techniques.
Increasingly, people watch online videos for educational purposes. YouTube, given its age and widespread use, may be the most significant platform for this. However, the majority of videos on the platform are intended for entertainment. As of 2021, the estimated user base of YouTube reached 2.24 billion (Ceci, 2022). Moreover, in a US YouTube survey, 86% of YouTube viewers said they often use YouTube to “learn new things” (YouTube Learning Statistics, 2017). US nationality makes up the second largest demographic on YouTube, consisting of 240 million users (Ceci, 2022). YouTube's digital videos are referred to as content. Content is published by both large entities and the users themselves through so-called channels. Meaning content takes the form of a product created by both the individual users, and commercial giants such as music labels, film studios, car manufacturers, and YouTube itself—as a company (not to mention the US Army). To put the number of videos that populate the platform into perspective, and to show its widespread coverage in the area of learning, YouTube states that there are more “learning-related” videos on YouTube than books in the Library of Congress (Learning-Related Youtube Statistics, 2017). As a deposit for information, this is substantial. Yet, this statistic fails to address the validity of the content, as well as what videos YouTube qualifies for this category. As some researchers argue, YouTube videos need to be moderated in order to verify its validity when shared for educational purposes (Terantino, 2011 & Chtouki et al., 2012).

There are many YouTube channels that concern the teaching of digital arts. More specifically, some of them focus on 3D animation, and subsequently also rigging. When analyzing the range of video tutorials on YouTube, those that do discourse rigging are often of the shorter format; 5-10 minutes. They give quick tips and step-by-step instructions to its viewers. However, these videos often lack substance and rely on their ease of access. A channel's focus is often to cover a broad area in order to yield hits when someone is searching the internet for a solution to a problem. Hence, channels tend to address common issues without problematizing the methods addressed in the video. The videos that target novice users are often about automated rigging tools or the built-in tools in the software. Nevertheless, there are also some in-depth resources available, especially on the subject of character rigging, but most of them fail to allow novices into the process. To put it short, online videos tend to focus on either automated rigging tools aimed at novice animators, or rigging concepts and solutions aimed at character riggers. In the main, there are two problems with learning rigging through on-line videos:

1. There is a big gap in content between the rudimentary and the advanced, making it difficult to progress from one level to the next—in terms of knowledge acquisition.

2. There is very little content to find about the fundamental aspects of rigging, which are essential to form a profound understanding of the medium.
2.5 Student survey

In order to provide a full background for the problem formulation, a survey was sent out to discern students' thoughts and habits regarding the subject. It was sent to students at the University of Skövde's game programs through the official channel for general information (i.e. for announcements such as events, job applications, surveys, etc.). It was stated and aimed towards students that had experience or interest in animation production.

The survey received 19 responses. 57.1% male, 33.3% female and 9.5% non-binary. 52.4% of respondents were currently enrolled in the bachelor level games program with focus on animation. A total of 47.6% in their first year of studies.

Answers were given through 5-point rating scales (for example, “Not at all (1)”↔“To a high degree (5)”) and multiple-choice or multiple-answer questions, sometimes with the option of free-text answers. Some questions were asked depending on prerequisite answers. Next is a summary of the answers.

Respondents were asked to rate the creativeness of rigging and animation. Animation was rated higher than rigging, see figure 1.

**Do you consider the process of .......... to be creative?**

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<thead>
<tr>
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<th>Animating (Mean 4.5, stdev 0.8)</th>
<th>Rigging (Mean 3.3, stdev 1.2)</th>
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<tbody>
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<td>Not at all (1)</td>
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<td>To a high degree (5)</td>
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**Figure 1.** Level of perceived creativity ($N=19$).

Respondents got to assess their own anxiety in relation to both math and rigging. They rated the frequency of their anxious reactions: 18 out of 19 experience math anxiety when faced with math calculations, at least sometimes. 13 out of 19 experience anxiety when rigging, at least sometimes. Subsequently, they also rated the strength of anxiety for when it occurs. The most important data point regarding anxiety strength is found when comparing the standard deviation between math- and rigging anxiety strength, see figure 2. The rigging anxiety strength is much more erratic. Yet, there is no clear relationship between respondents who experience rigging anxiety and their math anxiety strength.
Figure 2. Comparison between anxiety strength for math (N=18) and rigging (N=14).

Moreover, respondents were asked if they saw similarities between their math anxious reactions and those prominent when rigging. Notwithstanding the previous datapoint, 67% did find similarities. This means that respondents perceive similarities to match anxiety even though there is no correlation to its strength. When looking at the free-text answers to this question, one thing becomes clear. Respondents focus mainly on the demeanor of new information rather than logic and counting like processes—that are directly linked to math anxiety. See answers:

“Since I don't animate or rig very often, the anxiety that I experience comes mostly from the feeling of inexperience rather than the actual rigging."

“Both forms of anxiety stem from worrying if I forgot an important step. My anxiety connected to rigging has however gotten better since I have more experience now.”

Respondents were also asked to state at which times they experience anxiety when rigging, see figure 3. Out of the 14 respondents who experience anxiety when rigging, almost everyone (12) do so when solving errors. Next closest is when “searching for new information”, which 4 experience.
Respondents were asked to rate the perceived level of stimulus in different areas based on their own experiences, see figure 4. “Doing chores” got the lowest grade, which is in coherence with theories on working memory and cognition. Furthermore, rigging is ranked higher than animation, this also matches the theories’ disputation, as it involves more problem solving.

Respondents rated how often they ask for help or feedback regarding several aspects of work, such as asking for help when animating, or feedback when rigging, and vice versa. The answers have been compiled into a combined average in order to gauge the likelihood of asking for help or feedback from teachers and peers (average 3.09, stdev 1.35). It was then compared to the grade of “How positive do you feel when you manage to solve a rigging problem by yourself?”, see figure 5. A correlation can be found between the two. The more positive a respondent feels when solving a rigging problem by themselves, the more likely they are to ask for help or feedback.
**Figure 5.** Frequency of asking for help/feedback -vs- positivity of solving rigging problems yourself (N=19).

When comparing the self-assessed proficiency to the current level of education, the infamous “Dunning-Kruger effect” (see cognitive bias of Kruger & Dunning, 1999) appears, see figure 6. The self-assessed proficiency of rigging has a peak in the second year, and valley in the third. Key-frame animation sees a dip in the second year already. Note that animation is taught before rigging in the program. The sample may have been made too late to get an accurate measurement for animation proficiency, and the first peak—as defined by the Dunning-Kruger effect—may have already developed by this time. This is probably why the bottom end of the peak is not visible in the graph. Nevertheless, the peak in the first year is significant and a valley is formed in the second year instead.

**Figure 6.** Self-assessed proficiency across education levels (N=19).
In accordance with traditional results on math and math related subjects, female respondents rated their rigging proficiency lower than male in the self-assessment. Moreover, female respondents' ratings had a wider gap between rigging and animation, both for the self-assessed proficiency and the perceived level of creativeness, see figure 7.

**Figure 7.** Comparison between female and male—creativity and self-assessment ($N=18$).
3 Problem

There are many tools available to make rigging effortless. Those novice to the subject, such as students, often believe it will be easier to use these tools. But there is a difference between easier, and faster; which is the real intent of the tools. The latter may sacrifice quality in favor of speed. The tools in question are: part-automated rigging processes and rigging packages containing prefabricated parts. The tools build the functionality for you. Commonly with an array of options, should be added, but automated nonetheless. However, the point is not to speak ill of automated rigging procedures. It is a good thing. Maybe even a necessary device in becoming efficient in this subject. However, as the argument goes, one must understand the concepts involved in these tools to truly benefit from them. To understand them, and to apply them correctly.

“Give a small boy a hammer, and he will find that everything he encounters needs pounding.”

- Abraham Kaplan

Oftentimes, this error is given to the students by the instructor. A finished rig is regularly given to students, intended as inspiration, as if to say: look, this is how it should work. However, it is subsequently also a ready-made solution to a problem. A rigging-scheme is the same whether the student is handed the finished rig itself, or just the instructions for making it. If the student does not understand this when using it, they easily fall into pitfalls. Observing a ready-made solution to a problem may trick the student into believing that it is going to be a perfectly good solution to other problems too. But it is rarely ever a perfect fit. Thus, they may force it to fit, and in doing so, break the pillar that maintains the rigor of the solution to begin with. So, observing a finished rig is good if you can deconstruct it, but easily misleading.

As the problem unfurls, the core of teaching rigging is to make the student see rigging for what it is: problem solving. In the subject of rigging, problem is the word. It is problem solving through-and-through. Subverting the problem and falling back on automatic or ready-made solutions is therefore to compromise the problem. The pedagogical benefit comes from the epistemic principles. Described in the words of epistemology, the benefit is to possess procedural knowledge (knowing-how), rather than just descriptive knowledge (knowing-that).

To summarize, in the methods for teaching rigging, there are three main problems that may occur:

1. Advanced rigging-tools and techniques are used. Therefore, focus is not on the core concepts. It is arguably better to scale down the complexity of the solutions if this facilitates a wiser understanding of the subject.
1. Rig-instructions and guides are handed out. The problem is seldom explained, only the solution. Hence, it is just descriptive knowledge. It is arguably better to facilitate procedural knowledge for the subject of rigging.

2. Rigging and animation are taught in parallel. Both contain their own parts respectively. However, they do not interact intersectionally. It is arguably better to anchor the rigging in the desirable movement.

### 3.1 Research Questions

This research aims to find a way of describing rigging concepts on an abstract and universal level. To free it from all technical bonds. Therefore, the research takes place on rather rudimentary ground. The reason to find a way to make it work comes from the deliberation of its pedagogical benefits. The pedagogical question becomes: is it a good way of teaching? The argument for it being a good way of teaching is quite simple; understanding a problem is better than knowing what makes the problem go away. This, in turn, provides an understanding of the solution. Altogether, it is theorized to bring the user an understanding of the subject on a profound level. Hence, the user—student, is in focus. Followingly, the research questions become:

**RQ 1.** How can rigging be taught in terms of procedural knowledge?

**RQ 2.** How can rigging be taught with focus on method rather than solutions?
4 Traditional and new definitions

4.1 Rigging

Looking at the word rigging, historically, the system of ropes or chains on a ship is called rigging. It is a system to support just as much as it is to control. On a ship, the ropes used to support a ship’s masts are called the standing rigging. Those used to control or set the sails are called running rigging. In game animation, the mast can be likened to the mesh of a 3D model, for it would stand, but not move without the rig. The running rigging would then be the skeleton and the controllers, as they are used to deform the mesh into multiple different poses. The essence of rigging is functionality and effectiveness, this is true for both marine vessels and animation. An engineer builds the ship and a captain sails it.

The role of the animator can be likened to that of the puppeteer behind a marionette. A marionette is a puppet controlled from above by a rod and strings (or wires). Each string is attached to a specific location on the puppet and used to move that part of the puppet, such as an arm or a leg (McCormick & Pratasik, 2005). This is still similar to how a ship’s rigging works. However, in the 1800’s, creating the puppets and performing with them were not necessarily two separate things, as the performers themselves often made the puppets (McCormick & Pratasik, 2005). In this case, the engineer and the captain are the same person. This remains mostly true for animation today, the animator may not create the character mesh, however, they often need to create the rig for it.

In the case of a marionette, the audience does not pay attention to the strings. The strings become invisible under the disguise of the performance. Moreover, in some puppet performances, the performer even designs the puppet with the intention to hide their hand or draw attention from it (McCormick & Pratasik, 2005). In game animation, the rig is completely invisible to the audience. Once the animations are finished, the rig’s controllers are deleted and the skeleton is rendered invisible in the game engine. Only the mesh of the 3D model is visible in the game. However, the skeleton can still be accessed, it is not gone. Accordingly, it is possible to utilize the skeleton functionality in the game engine. A character, for example, can pick up an object—say, a coffee cup, and thanks to the skeleton, the position of the hand is known. The coffee cup can follow the joint in the hand directly.

In traditional animation, rigging is not necessary. When animating with pen and paper, the only “rig” you need could be defined as the table that holds the paper. With the use of registration pins and a paper (celluloid) with matching registration holes, you can accomplish perfect placement of the paper every time. Yet, it is not mandatory, you could theoretically just hold the paper very still. It is a convenience type-of-rig rather than a strictly necessary one. It does not give functionality, it provides ease-of-use. However,
central to this argument, the ‘rig’ allowing you to animate with pen and paper (a table with registration pins) is easier to understand than the rig of a digital character. After all, it could be explained pretty well in just five words within those parentheses. The cognitive process of understanding why and how it works is to a high degree physically related. We intrinsically understand that the pins and holes restrain the paper from moving, because everyone has written on a piece of paper at some point in life. We know how paper acts. And we understand that accidentally moving the paper is not desirable when drawing on it. On the other hand, it is much more difficult to grasp for the digital subject as there is no frame of reference, nothing to relate to, it is completely conceptual.

4.2 Technical creativity

Typically, when asked to mention a creative profession, one might think of painters, musicians or architects etc. In the main, traditional arts often spring to mind. For some, game developers may also come to mind. Probably if you are a game developer. There are many aspects of game development that are similar to the traditional arts as they are directly derived from them. Animation is one of the youngest art forms that has been applied in game development, seeing that the craft itself is not much more than a hundred years old. Rigging is seldom seen as a creative part of the animator’s process. One possible reason for this could be that there are many automated tools at the rigger’s disposal. Tools that generate functional rigs at the press of a button. One might wonder: How could something that can be automatically generated ever be creative? The inherent notion is that those two are mutually negating each other.

In reality, the process of animating is not to splosh paint on an empty canvas. Animation must consider the movement already when the rig is to be created. Animation is similar to architecture in this way. There is a design that must withstand the restraints of construction. In architecture, the challenge is to allow a design to shine through the technical solutions making it a reality. So, there is a design. One must just understand the connection between a column's structural functionality, and the decorations on it, for example. Likewise, the animator must also understand the connection between animating a movement and enabling the movement through the use of rigging.

As discussed earlier, when drawing in traditional animation, one can use this understanding of the medium, to think of ways to restrain the paper from moving. Importantly in this situation, the problem is known and clearly defined: The paper should not move, yet be removable at will. As the example was; a paper with registration holes. However, there are many ways to achieve this. This is where fluency comes in. There are more methods that can be discovered. You can use a table with a frame corner and place the paper in that corner. This method is not as effective, on the other hand it makes it easier to place the paper quickly. In another method, you could just position the paper where it should be and use clamps to keep it down. Not very precise, but gives a lot of freedom in placement—if that would be desirable. As these examples demonstrate, you can also find new information by experimentation. This, in turn, makes the problem more
nuanced. Testing or theorizing multiple ideas makes the learner more competent about the problem at hand.

4.3 Digital Content Creation Software

The end product of game development is of course the game. Yet, as it is now, production involves the creation of sub products such as 3D models, textures and animations (Cooper, 2021). These sub products are called assets. Assets are then amassed in the game engine—the literal engine that drives the game. Assets are made in the Digital Content Creation (DCC) software like Maya, Max or Blender (Maya being the most well-established). Although, in the future, more creative assets will likely be created in the game engine itself (Cooper, 2021). On the other hand, we see efforts made by some game engines to try to obey the expectations set by the process of rendering 3D works directly in the DCC, and in doing so, they remove the need for manually optimizing assets for use in the game engine. As of writing this text, however, they are yet to succeed in doing so from a technological standpoint, and the efforts mainly regard 3D modeling and lighting rather than animation.

Looking through the eyes of media theory, a DCC is an opaque form of media, meaning that the user is aware of the software at all times when using it (Bolter & Grusin, 1999). For, the assets made in the software are not only rendered on screen as final images, moreover, its components and attributes are also stated through many other windows. The most telling thing about the opaque nature of the DCC is the blatant list of all objects that currently exist in the file. In Maya this list is called the Outliner window, see figure 8. In this text, Maya is used when giving practical examples, because it is a well-established tool for creating 3D-animation. But the rigging concepts are not connected to any particular software; they are just that: concepts.

To understand rigging, one must understand the DCC. It is easy to see the similarities to the stages of a child's cognitive development. As Piaget argued, if a child has not yet reached developmental maturity, no amount of experience will make it respond in the desired way (Piaget 1950). The correspondence of this in rigging is clear. The same can be said about the learners' maturity and understanding of the DCC. The learner must first be amenable to the circumstance to be able to critically think about what is happening; to reflect on doing. If the learner is struggling in using the DCC, it will be difficult for them to see through the opaque media interface and appreciate the underlying concepts. Hence, they do not reflect. They would simply have to struggle just to stay afloat.
Maya is constructed with the idea that all objects are presented to the user all the time (Nieto et al., 2018), everything is at your fingertips. Maya is a node-based software. Meaning that every object is also represented as a node in a graph. You can select any object and add it to the graph by the press of a button. The user can then observe these nodes for a more structured view of any given object, see figure 9. Yet the nodes do not foretell the form of an object, instead it tells the relation it has to other objects in the scene. For example, take a NURBS (Non-uniform rational B-spline) curve being used as a controller to drive the rotation of a joint—figure 9. The nodes of the curve in the graph do not describe the form of the curve in 3D space. Instead, it describes the relationship the curve has to the joint. One is controlling the other with an orient constraint—the two nodes are hence connected by a third node in the middle.

![Figure 9. Graph window displaying a curve and joint connected by a constraint.](image)

The nodes can represent a variety of things. For example, a transform node is a coordinate in world space, and a shape node holds an object's geometry attributes (Node Types / Maya 2018, 2018). A shape node is the child of a transform node. A transform node has only one shape node. To make this clear (and still be able to present all the information at once), Maya has different types of shape nodes to represent certain objects (Nieto et al., 2018), see the different icons on the nodes in figure 9. What they all have in common is that they visualize functions so that the user can construe the logic behind them.

Note that in figure 9, the shape node of the curve is not connected to the other nodes, not even to its own transform node. You might expect these two to be connected in the graph, or even to be contained under the same node, but they are not. Because there is usually no interest in even displaying the shape node in the graph. The hierarchy is not represented in the graph, only in the outliner. The Outliner declares the hierarchy of all transformable objects—objects that can be positioned and moved. To make this clear, every shape node is placed under a transform node in the Outliner (assuming they are made visible by enabling “Display→ Shapes”), indicating that the shape is dependent on the transform to even be rendered on screen. After all, an object must have a placement in the world to be, for if it is nowhere, it would simply not be (or at least be invisible). Altogether, to understand the software one must understand the relationship between objects in both the graph and the Outliner window. Both windows’ have unique and independent purposes in the software.
4.4 The concept(s) of rigging

The rigging concepts listed next are, as theorized by this text, a way to make rigging less intimidating for students. It introduces them to the concepts of rigging one by one. In this way, learning stages become easier to grasp as they persist as isolated experiences.

These concepts were defined and written down during the construction of the workshop. To the furthest extent, they are generalized. Not to be software specific. Not even limited to 3D creations. Some rigging concepts are pure logic, some are technical functions, while some regard media theory. They do not necessarily have an internal order, but the order presented is derived from pedagogical deliberation.

- **Hierarchy** - An object may move according to the movement of another object if it is placed under that object’s hierarchy. It is like connecting objects together without them having to be physically joined. One object is a parent, and the other its child. This relationship can be repeated in a chain ad infinitum.

- **Joints** - (Also called bones), are a point in space. They have one extra functionality over ordinary objects, namely the ability to set a weight influence for individual components. The hierarchical joint structure of a rig is called a skeleton.

- **Skin weight** - The vertices of the 3D model’s mesh (mesh components) are deformed by joints according to their set influence. Skin weight values are stored in the vertices. Multiple joints can share influence over a single vertex.

- **Empty** - An object without a shape is called an empty. Also referred to as “null object” or “group”. Empties are used to arrange objects in the scene using hierarchy.

- **Kinematics** - Is the study of motion without regard to the cause of motion. Movement in a hierarchical structure is by default Forward Kinematics (FK), where an object inherits its transform from its parent. Moreover, there is also Inverse Kinematics (IK), where instead the end joint of a chain dictates the transform of the other joints. The angle of all joints in the chain are calculated to achieve the desired position of the end joint—effectively reversing the joint chain.

- **Attributes** - An attribute is a numeric value and can be many things; for example, the rotation of an object in degrees, or the height of an object above ground, or even the number of spokes on a wheel. An attribute can even be created completely arbitrary.

- **Driving** - The value of one attribute may dictate the value of another attribute, even on another object. This may be done while simultaneously applying different types of mathematical operations, such as add, divide, multiply, etc. For example, if the character jumps high, there will be more spokes on the wheel.

- **Constraint** - An object may inherit its transform attribute from the transform attribute of another object. The concept of hierarchy can be simulated through a constraint of type: parent. However, unlike hierarchy, it is not a fixed relationship, it can be toggled.
• **Controllers** - Are ordinary objects without any special attributes. They act as handles to make it easier to navigate and control the skeleton. Constraints are used in order to formulate this relationship. *Controllers* are rendered as lines and modeled into figurative shapes to represent the part they control: a foot, a clavicle, a finger, etc.

• **Morph target** - (Also called *blend shape* or *shape key*), the position of all the vertices of a mesh can be saved as a morph target. The morph target can then be blended to via an attribute. Moreover, it is possible to blend between multiple morph targets at once.

• **Resolution** - as a measurement, is defined by the number of components that sustain the desired deformation. Resolution has two aspects. First, the number of joints in the rig dictates how gradually the rig can bend. Secondly, the number of vertices on the 3D models mesh determine how well the 3D model can follow the bend of the rig.

• **Compatibility** - The functions and components that are used to deform the vertices have to be considered when the assets are exported from the native software into another software—often the game engine. Technological compatibility must be ensured between the two or more softwares to ensure correct functionality.

There is, of course, a technological interaction between the rigging concepts and the animation methodology. The technique of animating is Spacing & Timing (Williams, 2001). Or in computer language: *key*. A *key* is the value of an attribute that has been saved in relative time. Meaning the role of the animator is to save numbers in a time-line. Hence, the relationship between the two aspects is best represented in graph or dope-sheet form; value across time, see figure 10. The *keys* are grouped under so-called *frames* when animating (this is derived from the traditional analogues method of cel animation). For example, a repeating and seamlessly looping walk cycle animation could be 28 *frames* long. However, in the computer, time is a float value and not numerical. This arrangement is simply a form of *remediation* (Bolter & Grusin, 1999). Furthermore, the real time of 28 *frames* is dependent on playback speed—commonly set to 30 *frames* per second (fps) in game development.
There are aspects of rigging that can be considered fundamental, then there are those that are more distinct for game development. With stating game development, it is applicable to really just about any application that utilizes techniques meant to optimize for real-time rendering. Yet, for this text, the focus is game development.

When animating a moving and deformable object for a game, there are certain limitations put on that movement and deformation. Practically, this means that a lot of things can be done in the DCC that are not compatible with—and can be exported to—the game engine. Typically, the game engine refers to joints in order to deform vertices. The mesh is connected to the joints of the skeleton through linear blend skinning, due to its stable and efficient computation (Mukai, 2018). Sometimes, morph targets are also used in order to produce nuanced poses that can look vastly different from each other, hence, not achievable with simple linear deformation. For instance, different facial expressions. Moreover, when rigging characters (or other biomechanical structures), morph targets can also be used to solve issues with complex areas of the body, where linear deformation struggles to suffice, the groin and buttocks, for example. It can also be utilized to improve naturalism, by morphing into the flexing of a muscle.

Not always, however, is the pose itself the problem. Sometimes the desired pose is already technically achievable. The problem, then, comes from the method when animating, it has to be effective. To exemplify, when animating a character walking on the ground, the animator is fighting to prevent the feet of a character from cutting the ground. It is obvious how to stop it, just reposition the feet until they have good contact with the ground. However, it is not effective to do so manually, time after time again. So, a better solution is desirable. Accordingly, the feet are rigged with IK-functionality. This allows the feet to be controlled independently from the hips of the character, while still being connected to the same skeleton through the legs.
When rigging, the goal is to cover all possible movements that will be animated. With optimization in mind, however, not all possible solutions can be implemented. Likewise, if a part of the 3D model will not move, it will not be rigged. Although, this is seldom the case. Usually, every part of the 3D model is rigged. So, the question of optimization concerns the whole 3D model at an earlier stage of the production pipe-line. In the rigs of marionettes, characters with long skirts rarely had any leg strings and thus lacked the ability to control them. Some of them did not even have legs at all (McCormick & Pratasik, 2005). On the contrary, in game animation, sometimes the rig for a leg may be added even though the character’s 3D model is missing that leg. This is done to preserve certain functionalities in the game engine and to enable reuse of animations between different characters. Although, probably not a walk cycle animation in this case.

The concept of resolution is particularly important when the rig is subject to limitations due to performance. Depending on the make of the game and target platform, the 3D model may have a particularly restrictive topology, with very few vertices. Moreover, the game engine often enforces strict limits on joint count too.
5 Method

5.1 Study Methodology

A case study was conducted. Participants were divided into two groups, A and B, 3 students in each (6 total). They partook in one of two different workshops. Group A was a control group and group B participated in an alternative workshop that taught rigging through the implication of rigging concepts. The workshops are explained under chapter 5.5 and 5.6. Students were not told that there was a difference between the workshops, nor were they told about the contents of the workshops beforehand, only that the workshops were about rigging and that this was an opportunity for them to give feedback on the teaching methodology applied at the university. Participants were interviewed after the workshop.

5.2 Participants

Participants of the study were all first-year students enrolled in a game development program at University of Skövde, with focus on graphics—animation. Students had attended university to study animation for a total of 8 months at this point. Moreover, they had studied character rigging as part of one previous course.

The target group was selected because they had recently taken their first steps in learning rigging. This meant they were new to the subject yet still had some experience. Moreover, the experience was still fresh. In addition, first-year students still have an active role in shaping their own education. This motivates them to actively participate in such a study.

5.3 Data collection

In order to answer the research questions, the sentiment of the student is important. For an alternative pedagogical methodology to work in practice, the students' perception of the pedagogical methodology must be positive. Likewise to influence their performance.

The workshop was followed by individual interviews in order to collect qualitative data and discern students' thoughts and opinions. The interviews were semi-structured to allow the participant to continue the discussion themselves in a direction of their interest. This also prevents asking questions in a stilted way. However, this is at the expense of the ability to strictly compare responses between participants, as the open-ended nature of the interview questions may result in varying discussions. Questions were also kept non-explicit so as not to lead the participant to a certain conclusion. This made it possible to study the participant's reasoning—without being too direct. For example, no interview
question stated anxiety by name, instead, the question was phrased like: “How confident did you feel when you started the test?”, to try to guide them in this direction.

The number of participants was limited due to the inherent size of the relevant class. Hence, quantitative data would be less significant. Because of this, quantitative data was only collected where it could be done so non-intrusively, i.e. where participants did not have to actively submit the data themselves. Rather, where the data could be extracted without the effective involvement of the participants. For example, by looking at the work they hand in at the end of the study.

5.4 Study procedure

Group A and B participated in different workshops, see figure 11. Both workshops contain materials that completely overlap with each other, but they are taught in different ways. The overlap can be designated with the meaning of the following concepts: Hierarchy, Constraints, Driving & Kinematics, as defined in chapter 4.4.

- Group A is taught a rigging solution in a step-by-step manner using a guide—called the Regular workshop. This facilitates descriptive knowledge (students know what the steps in the guide achieves).

- Group B is taught with an approach of experiential learning by elevating and demonstrating rigging concepts—called the Concept Workshop. This facilitates procedural knowledge (students know how the concepts work).
Figure 11. Flowchart depicting the progression of the Regular and Concept workshop.

After each workshop there were two tests, see figure 12. This means that both groups completed both tests, see figure 13.

1. The first test requires a specific solution—called the Specific test. It is stated through an assignment description, meaning definitive goals are declared (see appendix A). This is meant to facilitate convergent thinking.
   - This is the exact same rigging solution that group A has practiced for in their workshop.

2. The second test is open-ended and can be solved in multiple ways—called the General test. It is stated through an assignment procedure (see appendix B), meaning no definitive goal is declared. This is meant to facilitate divergent thinking.
   - Neither group has practiced for this assignment, yet both groups have been taught methods during the workshops which they can use to solve it.
Figure 12. Flowchart depicting the progression of the Specific and General test.

Figure 13. Flowchart depicting the overlap between the workshops.

After the workshop and the test, students were invited to join individual interviews about their experience.

5.5 Regular workshop

The following procedure describes the design of the rigging guide used in the Regular workshop for teaching rigging.

Students follow along as the instructor demonstrates the steps of the rigging guide, effectively completing the rigging solution together with the instructor in class. The guide concludes the following steps:
• **Hierarchy**
  ○ Students add joints to build the skeleton of the arm.

• **IK/FK**
  ○ Students add an IK-solver to a copy of the joint chain: shoulder, elbow and wrist.
  ○ Students make another copy of the joint chain (one for IK and one for FK) and add constraints between both chains at once, then blend between them by toggling the constraints on/off.

• **Constraints**
  ○ Students use *controllers* to control the joints by using constraints.

• **Driving**
  ○ Students drive the constraints for the IK/FK copies of the joint chains by an attribute on the hand *controller*.
  ○ Students drive the rotation of all fingers by an attribute on the hand *controller*.

For a detailed description of the regular workshop, see appendix C.

### 5.6 Concept workshop

The following procedure describes the design of the artifacts used in the Concept workshop for teaching rigging.

The instructor showcases the following concepts one by one:

• **Hierarchy**
  ○ Students try to figure out the possible movements of the table lamp, and the instructor illustrates important moves that may have been missed (move the whole lamp, pull the head to stretch or contract the lamp arm, tipping the lamp foot, rolling the lamp foot).
  ○ Instructor shows a demonstration of the hierarchical implication underlying the abstraction of rotation order: \( z > y > x \) (i.e. the hierarchy of a joint; Gimbal mode).
  ○ Students try out the ball rig that has a decoupled functionality between ‘scale’ and ‘rotate’.

• **Constraints**
  ○ Students use *controllers* to control joints by using constraints.
  ○ Students use *empty*s to move the joints in its hierarchy without *controllers* (the example is the tipping motion of the lamp foot identified in the beginning of the workshop).
  ○ Students use constraints to make some joints—but not all joints—follow the lamp arm *controllers* (this demonstrates root joint functionality).
Driving

- Instructor demonstrates the functionality of a separate tilt and rotate controller on a disc.
- Students use the node editor to drive the mesh rotation with the rotate controller, this counteracts the spinning of the disc mesh inside the rig (the example is the rolling move of the lamp foot identified in the beginning of the workshop).

IK/FK

- Students add an IK-solver to a three-joint chain (the example is the arm movement of the lamp identified in the beginning of the workshop).
- Students make a short animation using the IK arm, then bake the animation and copy the curves from the joints of the IK arm and paste it onto the joints of an FK arm.
- Students add constraints between two joint chains at once; one for IK and one for FK, then blend between them by toggling the constraints on/off.

5.6.1 Detailed description of the Concept workshop

The subject for the concept workshop is a desk lamp. The lamp is a good candidate for introducing rigging because its form and movement complexity is fairly limited.

The first step is to observe. Before rigging a lamp, the student should handle a real, physical lamp to see how it acts when it is posed and altered, see figure 14. By handling the object, you get an intrinsic feel for its functionality. In addition, you can evaluate how many joints are needed and where they should be placed.

![Figure 14. Photo of a three-joint desk lamp.](image)

The students are given their first task. They must deduce the ways in which the lamp can move. So, they are simply asked: “In what ways can this lamp move?”. A three-joint lamp is
recommended because of the quantity of possible movements. Yet, the difficulty can be
lowered by opting for a two-joint lamp instead. This is meant to practice divergent thinking.
In this exercise, the student is exploring. It can be done either in small groups, or alone.
The lamp should be a so-called dummy, not a working one. At the introduction of this
exercise, the instructor could drop the lamp on the floor to demonstrate that it is not
fragile and to encourage the student to be exploratory in their endeavors.

The first exercise in the workshop is meant to make the student think: why does the rig
need a certain functionality? This anchors the rigging in the desired movement. Likewise,
this could also be done with regards to animation theory. For example, ask the student:
How can squash and stretch (as defined by Disney’s 12 principles of animation: Thomas &
Johnston, 1995) be achieved in a character’s arm?

As an extension of this exercise, printed symbols that represent joints can be handed to
the students. The student should attach them to the lamp to indicate how many joints are
needed, where they should be placed, and their hierarchical order (see figure 15). Meaning,
they should be placed wherever a joint is needed to accentuate the movement,
Furthermore, the tip of a joint should point towards another joint to indicate their
hierarchical relationship to each other. When the lamp arm is moved, the role of the joints
will immediately become very clear. Seeing them move through space will persuasively
illustrate the role of hierarchy.

![Figure 15. Printed symbol of a joint attached to lamp arm.](image)

After some time has been given for the student to investigate the movements of the lamp,
it is time to conclude the exercise. The student should present their findings to the
instructor. The student might find that it is possible to grab the foot or the head of the
lamp arm and bend it to an angle. Or, that you can grab the lamp and move the whole
thing. All of which are valid observations. They simply describe an action—Newton’s third
law (Newton, 1687). Your hands are acting upon the object. Either on the object as a whole,
or just parts of it. However, there are a few movements that should be demonstrated by
the instructor if not found by the student:

- The first movement is a scenario where the lamp arm’s three mechanical joints play
  a central role. If the lamp is placed on a stable surface, and the head of the lamp
  arm is moved by force, both the top and middle joints of the arm will move. This
  illustrates the principle of FK. In this case, a joint is moved by its own child,
  effectively reversing the hierarchy of the joint chain. Note, however, that all three
joints are actually rotating. Yet, the bottom joint will remain anchored in space. In addition, IK can also be achieved in reverse by instead placing the lamp upside down and moving the base.

☐ The second movement makes use of the lamp foot. By tipping the lamp to the side of its foot, this demonstrates that there can be hidden movements that are not formed by the mechanical make of the object. Meaning that this hinging motion is possible without the use of actual mechanical joints. Instead, this movement utilizes the edge of the foot as an elbow for the movement, temporarily giving it a pivot to rotate from.

☐ The third movement is performed by the lamp itself. The student might only think of ways in which two hands can move the lamp arm, like in the previous examples, not realizing the ways in which the lamp can affect itself through gravity. Here lies the possibility of momentum—Newton's second law. The momentum of a body is equal to the product of its mass and velocity (Newton, 1687). It is possible to give the lamp momentum by adding velocity. However, the example is not to send the lamp flying into the wall. Rather, to place the lamp on its foot at an angle and give it a spin. The lamp will now twirl around the edge of the foot, much like a coin spinning on a table. As the momentum eventually dissipates, the spinning is brought to a halt.

The first exercise was conducted with a real lamp—in the real world. Now, it is time to translate this experience into the computer.

The next step is to begin working in the DCC. The obvious thing might be to rig an actual lamp. However, as experiential learning argues, there must be time to reflect upon the experience before you apply it. Since this may be the first time the student comes into contact with the DCC, they should first do a short experiment to get accustomed with the DCC. This will also give firsthand experience with hierarchy in the computer.

As made clear in the study by Elyan (2012), the experience does not have to be in reality to be intelligible. As long as it is conducted in a format that is familiar to the student, the student will have the freedom to play around with and experience the mathematical concept. For the first step in the DCC, the student should rig a simple ball by just rearranging objects in the Outliner (i.e. no joints are used). The objects in question are just one controller and the mesh of a ball.

Here are the steps for the ball rig listed:

☐ The student is first instructed to inspect the ball by altering its transform values (moving, scaling or rotating it), see figure 16. It is important that the student has had this experience before beginning to rig it.
The student is then instructed to place the ball under the hierarchy of the controller in the Outliner. The ball will now inherit the transformations of that controller. The student should now try moving the ball again, this time moving both objects to form an understanding of the relationship between them.

For the last step, the ball should remain under the hierarchy of the controller. Now, if the controller is first scaled, and after that, the ball is rotated, the ball will rotate within the deformed shape of the controller (compare the poses of the balls in figure 16 and 9 for the expected result, with and without the rig).

![Figure 16. Simple ball: The ball is scaled and then rotated.](image)

![Figure 17. Rigged ball: The controller (square shape) is scaled, then the ball mesh is rotated.](image)

For the next exercise, students are handed a 3D model of the lamp with apposite joints already bound to it, see figure 18. As made clear in the first exercise of the workshop, the joints of the rig for the lamp arm should be created in accordance with the mechanical joints of the real lamp arm (see figure 15). In addition, one more joint has been added, called “Joint Base”. It can be seen as the deposit for all the parts (excess vertices) that should remain stationary when the lamp arm moves.
This exercise demonstrates the principle of the foot-roll. The foot-roll describes the action of the foot when it rolls over the heel up to the toes, or reverse. A practical example is the movement of the foot when walking. As made clear in the first exercise, this movement can also be done with the lamp base. Moreover, a lamp base is a well-suited limited substitute for a real foot.

Students are instructed to add two more objects to the hierarchy: two *empties*. See figure 18. Joints are used with hierarchy in the DCC software. One joint follows another according to a parent/child relationship. This relationship was made clear to the student through the first exercise. Yet, so-called *empty* objects can be used to establish hierarchy too. To clarify, using *empty*s can achieve exactly the same hierarchical relationship as joints can, and even be utilized when animating by moving joints. They are both mere objects in the DCC. However, only joints have the ability to deform vertices of a mesh (in a universal manner that can be used in the game engine). To summarize, *empty*s can affect joints, which in turn affects the 3D-model.

So, to allow for this movement, two *empties* are positioned at opposite sides of the lamp foot, right at the edge of it—one *empty* for each corresponding direction. One *empty* is placed under the hierarchy of the other, and the joint chain is placed under both *empties*. Now, if either *empty* is moved, all the joints it contains (and the joint's connected vertices, accordingly) will also move. Hence, if the *empty* is rotated, it will look as if the lamp is rolling over the edge of the lamp foot, see figure 19.
For the final step, controllers are added to enable efficient use when animating. The controllers are used with constraints to control the joints and empties. This makes it possible to rotate an empty without having to select it through the Outliner window, you can simply select its corresponding controller directly in the viewport. A so-called root joint is also added to optimize the rig for use in the game engine. Importantly, no controller is constrained to the root joint, it will always stay in the Origo.

It is time to take a look at a new window in the DCC: the Node Editor, which is utilized to achieve the concept of driving. Like in the earlier example with the ball, this rig will also not utilize joints or constraints, only simple objects.

In the next exercise, the goal is to enable the lamp foot to roll around its edge—the rolling movement from the first exercise. If you do not apply the aforementioned rigging solution, and the foot is tilted and then spun, the whole object will simply spin around its center, see figure 20. However, if you counteract this rotation with the rotation of the disc itself, see figure 21, only the angle will change, making the disc appear to roll around its edge when rotated, see figure 22.

In the figures below, the grid is visible, the disc has been colorized, and arrows have been added to make it easier to see the current effect. Pay close attention to the type of rotation.
**Figure 20.** Tilted disc rotating around its center.

**Figure 21.** Tilted disc rotating its geometry.

**Figure 22.** Tilted disc rolling along its edge (rotating around its center and geometry, both).

This movement has been likened to a coin spinning on a table. Note, however, that the rig does not accurately simulate precession—an effect that occurs when spinning a coin. That would require a more sophisticated functionality to achieve. This is just an estimate, only meant to be good enough for the animation.

The set-up of the rig in this exercise is almost the same as for the foot-roll, the fact is that it is a further expansion of it, just one more controller (or empty) and a simple math function is needed to make it work. The logic—the solution—is to negate the rotation of the disc mesh as it is spun around its center. So, for every degree the rig is rotated (see figure 20),
the mesh of the disc rotates (see figure 21) a degree in the opposite direction. It only takes three steps:

- First, create the hierarchy of the rig, see figure 23. The pivot of the controller called “spin_ctrl” is placed in the origo, it is used to rotate the disc around the center of the rig, see figure 20. The pivot of the controller called “tilt_ctrl” is placed by the edge of the disc, this is used to tilt the disc.

- Next, in the Node Editor, feed the “Rotate” attribute of “spin_ctrl” into the “Rotate” attribute of “disc_mesh”. This means that the value of the “Rotate” attribute on “spin_ctrl” will be copied to “disc_mesh”.

- Finally, the value must be reversed by adding a “Multiply-Divide” node in between, see figure 24. The “Multiply-Divide” has two inputs, with three values each, corresponding to “X, Y & Z”—in that order. In figure 25, input Y is yellow because it has an incoming connection from “spin_ctrl”. The second input Y is set to “-1.000” in order to multiply the first input with a factor of -1.

The roll functionality of the rig will now work. The object's rotation has been decoupled from its tilt, similar to what was done in a previous exercise with the ball.
Figure 23. Hierarchy (left) and 3D model (right) of the disc rig.

Figure 24. Node Editor displays a connection between two objects (a controller and a mesh), with a “Multiply-Divide” math function between.

Figure 25. A “Multiply-Divide” function where Input 1 “Y” has an incoming value (yellow field) that is multiplied by the factor of -1 by Input 2 “Y”.
The final exercise has two parts. These are meant to parse the inner workings of joints that are steered by diverse functions, such as IK. It demonstrates that IK-functionality is just a way of forcing movement on objects. For this exercise, three copies of a three-joint chain are handed to the student, the first is the default one, then a copy called “IK”, and one “FK”.

- Students are instructed to animate a move on the IK handle, so that the joint chain bends.

- Students add a constraint of type Parent from both the “IK” and the “FK” joints to the default joints, one at a time.

- The default joints now follow both the IK and the FK joints, 50% influence to each, ending up amidst both, see figure 26. Multiple objects can share influence over a single object. Moreover, the default joints now have two constraints that can be toggled on and off in the Channel Box window, so they can still be used independently as well.

![Figure 26. Default joints chain (black), with constraints to both FK (red) and IK (blue).](image)

Lastly, after experiencing how a movement can be copied from one joint chain to another by using constraints—regardless of the functions on that joint chain, the students are instructed to remove the constraints and copy the animation of the IK joints in another way.

- The students are instructed to bake the IK animation they created in the last step by selecting the joint chain and using: [Animation→ Key→ Bake simulation].

- By selecting a joint’s curve in the Graph Editor, see figure 27, the curve can be copied by pressing [Ctrl + C] on the keyboard. Next, it can be pasted on another joint by selecting that joint and pressing [Ctrl + V] in the Graph Editor. This has to be done for every joint in the joint chain.
The animation is now copied and the movement between the default and the IK joint chain will match. However, this time, if the IK animation is hereby altered, the default joints will not receive an update until the curves are manually copied again.

All the concepts that have been demonstrated throughout the concept workshop could be applied to the lamp's rig. Yet, they have been taught in a universal manner in the form of isolated experiences.
6 Analysis

The effect of the concept method is analyzed based on the results of the interviews and the submissions made for the test assignments. In addition, it is supplemented with observations made during the workshops and tests in the classroom.

Answers to interview questions are grouped under a separate subheading that cites the question. Not all questions are presented in the results, follow-up questions meant to get the respondee to elaborate their answer, for example, are not spelled out in the text. Moreover, questions are not necessarily presented in the order that they were asked in the interview.

Questions and answers have been translated to English. Answers were transcribed live during the interview.

6.1 Participants background

The students that participated in the study had varying levels of proficiency for the subject of rigging. Some seemed to have an easy time processing the workshop, and some struggled with certain tasks. In group A, Andrew was particularly proficient. In group B, Bella was adept but Benjamin struggled a bit more than other students.

No effort was made to alter the group compositions, this was done to facilitate the experience for the participants as much as possible. The idea was to get as close to a regular class as possible and avoid any awkward feelings a lab environment can evoke.

6.2 Results

By way of introduction for the interview, the students were asked an easy and narrow question, simply put: “Did you learn anything new?”.

“Did you learn anything new?”

Here, differences between group A (“Regular” workshop) and B (“Concept” workshop) already began to appear. Interestingly, not necessarily regarding the knowledge derived
from the contents of the workshop, but rather the acquisition of knowledge itself. As such, the discussion leads on the method for learning.

When asked this question, students in group A mentioned software features that they felt were new to them (for example the Node Editor and Component Editor). They enjoyed the opportunity to dive a bit deeper into this. They stress this as being insightful. They also mention that the workshop included some repetition—things they had already been taught. Yet, still claiming this was helpful for the learning process. Amelia stated that, now, they were more secure in their own rigging process. However, Andrew mentioned something different: “I don't understand all the steps we did [through the rigging guide]”. They are referring to one step in particular, namely the IK/FK switch. Nevertheless, they went on to say that they now knew how to create an IK/FK switch and that the workshop presentation was “fast and good”. This student did not appear to have difficulties following along during the workshop, this was expressed first afterwards—in the interview. They rounded up by saying: “you can't ask me how to do it now afterwards”, in a joking tone.

On the contrary, in group B, there was a tendency to point out that this workshop was different to what they were used to. Benjamin said that: “It's good to get to know what you need to improve on.”, insinuating that parts of the workshop were new to them. Bailey mentioned the first test—the arm. They said that: “[now, it's] much clearer regarding the arm part.” They said this despite the fact that group B was not taught how to rig an arm. They continued by saying: “Now I know how to use joints, it's stuck in my memory now.” In essence, Bailey’s comments reveal that they perceived this teaching method to be more potent than what they were used to. Bella, on the other hand, even went on to state the differences verbatim. When asked the question, right away they said: “Yes, it feels more clear what I'm doing now”, and continued by saying: “when we had the first rigging assignment [in an earlier course], we were told ‘do this’, but never why.” They are expressing that this workshop had in fact told them why. Finally saying that: “I can do it without a tutorial now.”

Bella, who appeared to be relatively experienced, appreciated the rigging concepts the most. They also appeared to have an easier time grasping the concepts and also understood their underlying importance—as they plainly stated it had finally told them why. This raises a question: Did this experience enable Bella to channel their previous experiences into, and facilitate, experiential learning on a broader scale? Maybe it unlocked some things in their past experiences. On a different note, Benjamin's comment about finding out what they need to improve on is telling. They had found out what they did not understand. The concept workshop had informed them of what they did not yet know, and that is arguably the next best thing to gain insight in a subject. Now they knew where to look and what to study, because they had found a concrete gap in their own knowledge. Importantly, they were able to identify it themselves.

In terms of the goal completion and the resulting product, group A was more likely to finish the rig of the arm. Neither group was more likely to finish the rig for the toy truck, Andrew
was the only one to finish it at all. Nevertheless, the students’ prior skill level was the most crucial factor to their performance in the test. So, a proficient student always performed significantly better than a less experienced student, regardless of workshop version. Note, however, that skill was not formally measured. It is really just the student’s apparent skill.

“How satisfied are you with your own performance?”

Students in group A were more consistent in succeeding on the first assignment in the test—the arm. Although, they did not always appreciate how far they got. However, consistent with the results of the test, students in group A were more satisfied with their own performance.

Alexander put it succinctly: ”It was good”, followed by: ”The arm turned out well, although I’m not done with the toy truck yet.” Andrew said they feel very satisfied, and added: “I have learned a lot in a short amount of time.” Amelia said they were only ”relatively satisfied”, though with an optimistic tone, and continued by saying: “I didn't finish the arm, and didn't get very far with the toy truck, but it was fun.” Focusing on the feeling of the experience instead.

On the contrary, group B seemed less pleased. Bella, for example, avoided answering the question directly, saying: ”The arm was easier”, “I ran out of time for the toy truck”. Bailey did the same thing. Deviantly, they said: ”Fairly pleased that I managed to make [the skeleton of] the whole arm”, as if they were trying to look at it from the bright side. Benjamin said that: ”When taking the time into consideration, I'm fairly satisfied”.

After being asked about how satisfied they were with their performance, the focus of the discussion was pitched towards the test as they were asked more about what difficulties they had faced in it. Some students mention the lack of time for the test assignments. Students in group B appeared more stressed about this as they commented on the limited time for the test several times in the classroom.

“What was the hardest part about the test?”

All students mentioned the toy truck assignment as being particularly difficult, although Benjamin did not mention it by name. Moreover, students seemed to have the same difficulties in both groups, they found it difficult to even start working on the toy truck and spent a long time creating the joints for its skeleton.

In group A, Amelia mentioned the toy truck right away, saying they only managed to create the joints. Similarly, Alexander said: ”It was difficult to figure out where the joints should be positioned [for the toy truck]”. They went on to add that they wish they had learned about mechanical objects sooner—pointing out that they consider this to be a different type of
rigging from what they were used to. Andrew said that: “the toy truck was much more difficult [out of the two tests]”, and came up with the suggestion to add clear goals to the assignment description, like a list of functions. They continued to add two examples of such functions: “the truck can roll” and “the crane can move up and down.” These suggestions are in line with the look of the first assignment (see appendix A). By the same tooken, they continued by saying they wanted to find functionalities to add to the toy truck rig, but that: “it was hard to figure out something that was good.” Lastly, they stated that the rig for the arm was not difficult at all: “We had a clear step-by-step guide, I didn't really have to think. I just kinda followed the manual”.

Students in group B did not have any complaints about the assignment in itself. However, they also struggled with getting past adding joints to the toy truck. Bailey said it was difficult to get started. Bella said: “I didn't really dare to get started on the toy truck, all the components were stuck together [because the meshes were combined]”. And Benjamin said that: “It looks so complicated, but you can't get around it, you grow afraid of not understanding the assignment”, continuing with: “I have to focus a lot on the joint placement and it's hard to get past [this step] and keep on rigging”.

The make of the test assignment with the toy truck may in fact have been pernicious. Perhaps the divergent nature of this test induced harmful stress. Stimuli can be good for performance, but as has been argued before, if there is no concrete direction to move forward and apply your stress in, it can be detrimental because it then results in cessation. It could be that the open-ended test assignment did not give the students enough to go on. Constructing a clear list of goals like in the first test assignment would ruin the divergent nature of the assignment, however, a push in the right direction might be necessary even for this type of assignment. The assignment could, for example, state a mission that demands the use of an IK-solver. This could promote creative thinking as it requires the student to think about different ways to apply the aforesaid function in their solution, yet it is not too blatant.

"How confident did you feel when you started the test?"

Here, the answers among students were quite mixed. Furthermore, no tendency is found in any of the groups. Even so, group B seemed a little more frightened when handed the test assignments as they chatted a bit about test assignment 1 in the classroom.

Amelia said they were relatively confident: “Not one-hundred percent, but atleast fifty percent confident”—in a joking tone. Bailey exclaimed: “Not super confident”, followed by: “We didn't have a workshop that instructed the arm, you had to connect the concepts to new objects”. Meaning they clearly made the connection between the rigging concepts and how it can be applied in the test, even though they did not enjoy it. Andrew answered: “I had some feelings of panic about whether I would get everything done in time”, as they are referring to all the steps in the guide they had just done during the work-along part of the
workshop. They concluded by saying that the IK/FK part was harder than they thought. Alexander, on the other hand, answered: “I felt more confident about the arm”, followed by: “However, I ask myself which method is best for the arm”. They say this even though group A had acquired a guide for the full rig of the arm. Finally stating that: “but it's fun to try things out—trial and error”. So, they did not seem to want to follow the guide in minute detail during the test, but rather find the most suitable solution themself. Benjamin, on the contrary, did not seem to take the test as seriously as the other students, and was a bit avoidant to answer the question, saying: “I usually go in with an open mind, perhaps it is better to know as little as possible.” Adding that: “Since participation was voluntary, it felt more relaxed”.

Bailey and Bella had very different opinions regarding the usefulness of their prior knowledge for this test. Bailey relied on what they already knew, and said: “I was surprised by how much I remembered from previous courses”. While Bella seemed more skeptical to what they already knew, answering that: “It was very unfamiliar, it’s been a long time since we last rigged”, and went on to say: “And back then I followed a tutorial without knowing what I was doing”, adding that: “Now I could make the connection to the workshop just before, this was easier”.

Both groups seem to experience stress, and in some cases possibly even anxious reactions connected to the test. However, it is difficult to pinpoint whether any workshop version had a significant effect on students' anxious reactions. One exception is Benjamin, who at one point during the interview expressed that the concept workshop had helped to build their self-confidence. On the contrary, in group A, Andrew revealed they felt particularly stressed before the test because they had little confidence in finishing on time. Although students in Group B talked a little about this concern in the classroom, they did not reflect upon it when asked about their confidence in the interview. Nevertheless, they did wish for more time on the test when later asked about the classroom procedure. So, despite what looked like stress—and possibly even anxiety-inducing—on the surface, students in group B did not report being less confident during the interview. In group A, an incline in confidence seems to have come from having the guide to follow. As Andrew said when asked about what difficulties they had faced during the workshop test, they would not concern themselves with too much thinking on the first test assignment as they could just follow the rigging guide and get straight to work. Likewise, Bella mentioned on another occasion that they also did not have to understand much when following a rig guide.

“What did you think of the workshop contents?”

Overall, both groups were very happy about the workshop as a whole. Although, group B was more positive in regards to the workshop contents. Group A felt that some things could have been done a little differently and gave examples for improvements.
Group B highlighted the value it would have as an introduction to rigging. Bella said that: “This felt like a much better introduction than what was in the animation course [earlier in the education]”. Explaining that: “Now, I got to learn why you do something, and it serves as a nice introduction”. Benjamin expressed opinions on the same lines as Bella and went on to say that this content would have been: “a great introduction before starting to rig a character”, stressing the value it would have as an introduction before tackling more complex forms of rigging. They even summed it up by saying: “It builds your self-confidence”. Students in group B expressed other strengths with the workshop too. Bailey said: “it was interesting to have several examples, and all of them dealt with different things but still overlapped with each other”. Similarly, Benjamin said it was interesting to rig one part at a time, saying: “it was never too much to handle at the same time”.

In variance to this, students in group A focused on the technical side of the workshop. Amelia thought it was informative, and said it was: “Fun to see the Node Editor”, “Before, we only used controllers”. Adding that it was: “Fun to see a new part of Maya”. Andrew said they would have wanted to see the functions of the rig before creating it themselves. Adding that it would probably have made it easier to keep up in the workshop: “it would give a more structured feeling”. What they did not realize was the similarities this had to the experiential approach of workshop version B. They also continued to add that: “It would have been nice to be told specific functions [goals] for the toy truck, but I understand the reasoning behind not having that, but maybe it could have promoted a discussion [amongst students] in the classroom”. Alexander said it was nice to have a guide to follow, emphasizing the ease of having a rigging guide at hand. They also added that: “It was nice to get some example [settings] for good bind-options for the bind skin [function—in Maya]”, and continued by saying “I miss having workflow-tips sometimes, it felt very good to get that now”.

During the workshop, students from both groups mentioned that they appreciated the workshop and were happy to partake in it. Moreover, both groups noted and were pleased with the differences in the workshop procedure from the methods of teaching they were used to. This was unexpected because group A was the control group and workshop A was thus supposed to assume the traditional method for teaching, and not give the impression of being different. Nevertheless, the difference that group A pointed out was not substantial. They simply thought the workshop was an improvement because it was smaller in size than they are used to, both in terms of content and number of participants. They thought it was handy to study just one body part at a time—referring to the arm. They said that this made it easier to digest the content of the workshop. They also mention that they would normally rely heavily on rigging guides to solve problems, not to say this workshop was any different, but to point out that they gained valuable insights from completing the rigging solutions live in class while receiving step-by-step instructions from the instructor at the same time. In all, they thought this approach was more helpful. As such, the improvements they point out should be taken note of.
"Would you change anything about the classroom procedure?"

Group A had many concrete suggestions on improvements of the workshop and students wished for more technical information in the workshop and for the test. On the other hand, group B kept it brief. However, it should be noted that almost all students mentioned, at some point during the workshop, that they wished they had more time for the test. The time for the test was very short, given they only had one session to work on it. Nevertheless, they understood the limitation of this class because it was not part of the regular schedule of the education.

In group B, Benjamin said: “Maybe have a discussion before each test”, at the same time pointing out the benefit of collaboration between students in the classroom.

In group A, Alexander wished for some more general information about menus, such as the component editor. Adding that: “Maybe have little text-boxes with some tips and info in the guide”. However, they also continued to say: “I'm bringing the guide with me home, because I don't know if I remember it”. They did not seem to realize the contradicting nature of those two sentences—even right after one another. They were asking for more information while at the same time having trouble remembering what had already been taught. Nevertheless, Alexander’s goal was probably not to remember all the steps, but to collect the information in the shape of documents—as a storage of information, as they specifically asked to have it in the guide. On a different note, Andrew also gave a recommendation they thought could improve the workshop: “Maybe demonstrate a function first, which is later used in the [test] challenge afterwards.” They said: “Maybe present IK on something that isn't the same object [as in the test]”, and proceeded to give a spontaneous example for the test: “add IK/FK to a trunk instead”. Without realizing it, they had, once again, allude to some of the values of the concept workshop by this recommendation.
7 Conclusion

The first research question aimed to find a way to teach rigging in terms of procedural knowledge. To achieve this, the concept workshop focused on the fundamental concepts of rigging—breaking it down into its most basic parts. Given the results of the interview, when put to the test, the method theorized in this thesis seems promising in order to meet this pedagogical goal. Students in the concept workshop talked about the process and pedagogical structure, this affirms the concept of reflection on doing (Kolb, 2014). Moreover, students repeatedly confirmed that this workshop would serve as a great introduction to rigging. Alluding that it had filled them in on things they previously had not understood, or at least had difficulties in understanding. Moreover, one student outright mentioned that the concept workshop had, for the first time, told them why. This explicitly stated the epistemic goal of the concept workshop: procedural knowledge.

The second research question concerns teaching rigging with focus on method rather than solutions. It is connected to the first research question; however, it is about shifting focus rather than deepening it. All students were positive about the workshop as a whole, regardless of which version of the workshop they participated in. Everyone just seemed enthusiastic about participating. Nevertheless, the most substantial difference between the two workshop versions was the student’s attitude towards the workshop contents. Students in the concept workshop were positive towards the changes and went on to compare it to their previous teaching. Evidently, they did not even have to be asked directly about the differences, they were keen on pointing them out. This alludes that they were cognizant of their own experience (Kolb, 2014) and considered it valuable. On the contrary, students in the control group had more decisive suggestions about what should be changed in their workshop. As if they were focusing on the descriptive value that the assignment had—that is, the learning outcome, not the process (Kolb, 2015). Moreover, they also came up with recommendations that sometimes aligned with the goals of the concept workshop. So, to some extent, the students’ own suggestions for improvement correspond with those highlighted in this text. At the very least, it can be said that the students appreciate the inclusion of method in their teaching. Albeit, the most striking difference is the lack of changes that group B recommended, as if they were overwhelmed by the changes they had already addressed. Regardless of test results, students in both groups recognized the open-ended nature of the divergent (Guilford, 1968) test assignment—although not using those specific terms. Yet, they appreciated the difference when faced with it, even if they found it difficult to solve the assignment. By considering the learning of problem solving (Runco, 2014), the attitude of the student can make it the right method for learning.

It is not clear whether the concept method is more effective for novice users to learn rigging as students’ inherent motivation was not documented. However, undoubtedly, students’ motivation for rigging concepts increased as they were made aware of its effect. Given the consistently positive attitude towards the experiential (Kolb, 2014) approach, it is
possible that this translates into a better understanding of rigging methodology as they experience, and experiment with, the fundamental aspects of rigging in its purest form.

7.1 Future studies

If this study were to be extended, it would also focus on the concepts which are specific to game development. As previously stated, this study provides an introduction to the concept method in teaching rigging for game development, and game development is notorious for demanding compatibility. Therefore, one of the 12 concepts were called just that: “compatibility”. So, if the study was extended further, the effect of rigging concepts would be tested in an assignment that demands the implementation of the rig in the game engine. However, compatibility is a concept that envelops all other rigging concepts if applied in practice. Consequently, this would assume the workshop to be more advanced and is unlikely to work at an introductory level. Thus, an introduction to rigging in general might be necessary before targeting the game engine.

The logical next step would be to test it on students who are complete beginners to rigging in order to discern its effectiveness in practice, while also collecting metric data to allow for comparison. However, some alterations might be necessary as concluded in the analysis, mainly regarding the test as it is unclear whether the traditional test methodologies work for the concept workshop. Once a better way to evaluate the workshop is in place, future studies could focus on comparing performance between the workshops to verify its effectiveness. What is more, it may also focus on the opinions of more experienced students or even working professionals. The concept workshop could be tested on more experienced users—for example students in later years education—to determine their preference, and in doing so, take into account their level of learning.

A comparison of performance was not possible. First, skill would need to be measured to provide a point of comparison. To do that, students would have to take more tests, both before and after the workshop. Moreover, to compare performance between the groups in a quantitative manner, a larger sample group would be necessary. The data could therefore not possibly prove that any of the workshops made the student group better at rigging. However, confidence could be an important factor to performance. Although students in the concept workshop appeared less confident when handed the test assignment, this was not reflected in the interviews. Some students deduce that the traditional methodology entails very little engagement as they follow the rigging guide without thinking too much. This would be especially true during a test. Hence, it is more likely that the rigging guide from the regular workshop can act as a device to prevent stress and anxiety under test circumstances, rather than the concept workshop being a device to induce it. Accordingly, it is possible that the concept method signifies pedagogical setbacks if it is initially perceived as more difficult due to the perplexity in getting started with assignments. If the students are, for example, less likely to ask for help, it prevents a self-regulated form of learning (Zimmerman & Schunk, 2011). It should be investigated. Potential strategies to avert it could be discovered.
The effect of math anxiety was not measured in a quantifiable way. The interview touched on it, and one student even pointed it out themselves. However, just like with performance, a comparison was not possible. The addition of collecting such data would be beneficial in analyzing the effect of math anxiety in a direct manner. To successfully do so, test assignments specifically designed to distinguish math anxiety may be necessary.

Even if the concept workshop would not prove to be sufficient in supplying the student with an understanding of the rigging logic necessary to build rigging solutions on their own, it could still be an addition when teaching rather than a substitute—providing more options to fulfill a self-regulated form of learning (Zimmerman & Schunk, 2011). As the study indicates, an experienced student has an easier time to grasp the concepts than a novice. This also raises a potential point for future research. If the students already have significantly varying levels of knowledge, how can the teaching of rigging encompass students at different levels?
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Appendix A

RIGGING TEST 1
Human Arm

Rig the arm model. The rig should include the following:

**JOINT STRUCTURE**

The whole arm, including all fingers, must be rigged.

A maximum quota of 23 bind joints is allowed, for example:

- 1 joint for the shoulder
- 1 joint for the elbow
- 1 joint for the wrist
- 4 joints for each finger (20 total)

**FUNCTIONALITY**

**Shoulder position**
You can rotate the shoulder controller to raise/lower and extend/retract the shoulder position according to the natural movement of the clavicle.

**Finger curl**
You can use a single controller or attribute to curl the fingers and form a fist.

**IK functionality**
You can use an IK-handle to move the arm from the point of the wrist.

**Elbow aim**
You can use a locator to alter the direction that the elbow is pointing in IK mode.

**FK functionality**
You can use controls to rotate the shoulder, elbow and wrist of the arm independently.

**IK/FK Switch**
You can toggle between IK and FK functionality on the arm.

**SKINNING**

The arm joints should be bind to the model mesh with max 4 influences. However, the weight groups do not have to be refined—you do not have to do any skinning.
Appendix B

RIGGING TEST 2

Toy Truck

Rig the Toy Truck model. The rig should include the following functionalities:

**TOY TRUCK**

- Rig appropriate controls for the animator to use for the toy truck. What moves are relevant for operating the toy truck?
RIGGING THE ARM
Workshop description

This guide describes the step-by-step process of rigging an arm.

1. JOINT HIERARCHY

STEP 1
CREATE JOINTS
Create new joints according to the position of the shoulder, elbow, wrist and fingers of the arm.

Tip: Select two joints and press the "P"-key on the keyboard to place the first joint under the hierarchy of the second joint.
Appendix C

Page 2:

STEP 2
JOINT ORDER
The hierarchy of the joints should be the following:
Appendix C

Page 3:

STEP 3

JOINT ORIENTATION

Open the orient joint tool [Rigging > Skeleton > Orient Joint].

Use the following settings:

![Image of Orient Joint Options window]

*Tip:* Press the "Toggle Local Axes Visibility"-button with the joints selected to visualize the joint orientation.

Before orient: 

![Image of a hand with joints and axes]

3
Every joint should point towards the next joint in the hierarchy.

2. BIND MESH TO JOINTS

STEP 1
BIND SKIN
Select all the joints and the mesh and bind them [Rigging > Skin > Bind Skin].

Use the following options:

![Bind Skin Options](image)
3. CONTROLLERS

STEP 1
CREATE CONTROLLERS
Place a controller (NURB object) at the following joint positions:
- 1 at shoulder
- 1 at elbow
- 1 a little bit outwards from the elbow
- 2 at wrist

Tip: Hold down “V” when moving the controller to snap it to the joint’s location, hiding the mesh also makes it easier to see.

STEP 2
CONTROLLER HIERARCHY
The controllers should have the following hierarchy:

STEP 3
RESET CONTROLLERS
Select all the controllers and “freeze” their transformations [Modify > Freeze Transformations].
4. IK/FK SWITCH

STEP 1

JOINT COPIES
Make two copies of the shoulder, elbow and wrist joints.

Name them with an “IK” or “FK” prefix accordingly:

![Joint Copies Diagram]

STEP 2

ADD IK-SOLVER
Hide the regular and the FK joints so that only the IK copy is visible.

*Tip: Use the [Display > Show] and [Display > Hide] to hide or reveal objects.*

Use the Create IK Handle tool to add an IK-solver [Rigging > Skeleton > Create IK Handle].

When creating the IK handle, first select the shoulder joint, then the wrist joint.

STEP 3

JOINT CONSTRAINTS
In the Outliner; first select the IK, then the FK, and lastly the regular joint, while holding down the Ctrl-key on the keyboard.

![Joint Constraints Diagram]

With the joints selected, add a parent constraint [Rigging > Constraint > Parent].

Do this for the shoulder, elbow and wrist joints, one at a time.

**STEP 4**

**CONTROLLER CONSTRAINT TARGETS**

The table indicates which object to select first, second, and what constraint type to use.

<table>
<thead>
<tr>
<th>SELECT (1st)</th>
<th>CONSTRAINT TYPE</th>
<th>TARGET (2nd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTRL_shoulder</td>
<td>Parent</td>
<td>JNT_shoulder_IK</td>
</tr>
<tr>
<td>CTRL_wrist_IK</td>
<td>Point</td>
<td>ikHandle1</td>
</tr>
<tr>
<td>CTRL_wrist_IK</td>
<td>Orient</td>
<td>JNT_wrist_IK</td>
</tr>
<tr>
<td>CTRL_elbow_IK</td>
<td>Pole Vector</td>
<td>ikHandle1</td>
</tr>
</tbody>
</table>

**FK set up:**

<table>
<thead>
<tr>
<th>SELECT (1st)</th>
<th>CONSTRAINT TYPE</th>
<th>TARGET (2nd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTRL_shoulder</td>
<td>Parent</td>
<td>JNT_shoulder_FK</td>
</tr>
<tr>
<td>CTRL_elbow_FK</td>
<td>Parent</td>
<td>JNT_elbow_FK</td>
</tr>
<tr>
<td>CTRL_wrist_FK</td>
<td>Parent</td>
<td>JNT_wrist_FK</td>
</tr>
</tbody>
</table>

**STEP 5**

**BLEND ATTRIBUTE**

Select CTRL_wrist_IK and add a new attribute [Channel Box/Layer Editor > Edit > Add Attribute].

Add the following attributes:
- A Boolean called "IK"
- A Boolean called "FK"
STEP 6

**NODE CONNECTIONS**

Open the node editor [Windows > Node Editor].

In the Outliner, select the joint constraints and CTRL_wrist_IK.

In the Node Editor, press the “Add selected nodes to graph”-button.

*Tip: You can remove nodes by pressing the “Remove selected nodes from graph”-button.*

Connect the “IK”-attribute of CTRL_wrist_IK to the “JNT Shoulder IKW0”, “JNT Elbow IKW0” and “JNT Wrist IKW0”-attributes.

Next, connect the “FK”-attribute of CTRL_wrist_IK to the “JNT Shoulder FKW1”, “JNT Elbow FKW1” and “JNT Wrist FKW1”-attributes.
5. FINGERS

**STEP 1**

**FINGER ATTRIBUTE**

Add the following attributes on CTRL_wrist_IK:

- A Float called “Finger_Curl”
Appendix C

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STEP 2

FINGER CONNECTIONS

In the Node Editor, connect the “Finger Curl” attribute on CTRL_wrist_IK to the rotate attribute of the finger joints.