IPM STEM component 3 – Week 10

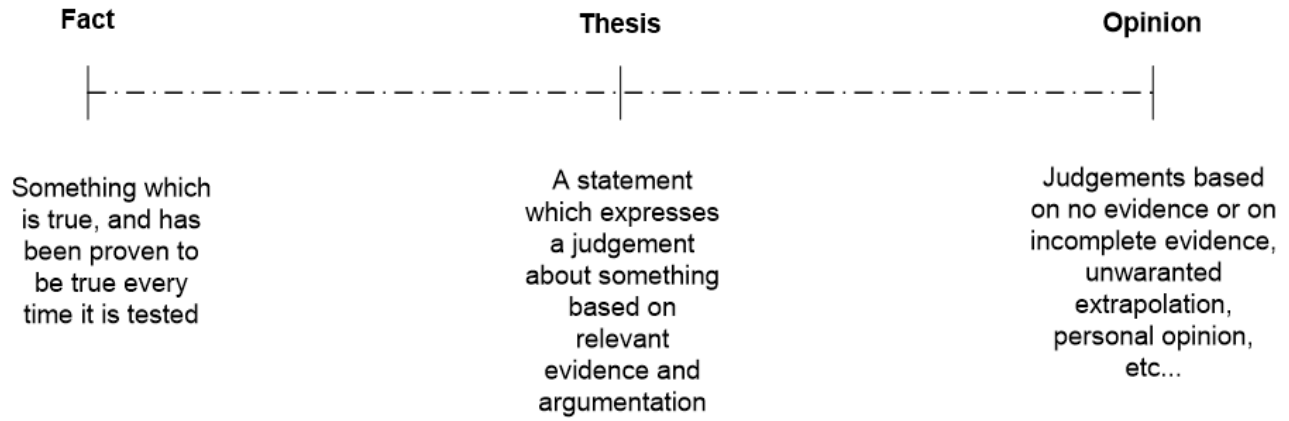
Thesis statement

Introduction: What is a thesis?

Here we will go through how to identify thesis statements as seen in example texts on mathematics. First we make a distinction between opinion, thesis and fact:

- *Opinion*: "I don't know if this is true, but I believe it is."
- *Thesis (or hypothesis)*: "This is something I can prove is true because I can test it by conducting an experiment and accumulating evidence in support of my thesis (this is done by analysing the data collected as a result of running the experiment).
- *Fact*: "This has already been proved true."

As a help we can use the diagram below to guide us when thinking about what a thesis statement is:



More specifically a thesis is something:

1. which makes a claim or states a clear position on a phenomenon, for example: "the extension of a spring is directly proportional to the force applied" (this is Hooke's law).
2. which can be confirmed via experimentation, and can be verify by other people by repeating or replicating your research;
    a. to introduce methods, data, results from articles
    b. we are not collecting data, so the data comes from other sources.
3. for which there is evidence, your own (collected directly from experiment), or other peoples' (presented in their papers).

4. which can be critically evaluated and argued in favour of, on the basis of the evidence.

Therefore, we might say that

"Hard/Strong" thesis statement = A claim as to the truth or validity of something, for which data and evidence can be collected in support of the thesis and which can be critically argued for.

An artificial example of a thesis might be as follows:

> "Previous work by Carter (1900) showed that it was possible to develop a measure of tastiness. This work was applied to the study of the tastiness of peanut butter sandwiches (Smith (1950) and Jones (2000)) where a measure of tastiness of 7% was found. In this paper I will show that the use of cooking method X and the ingredients of strawberry jam and brown bread leads to an improvement in the tastiness (variable) of peanut butter sandwiches of 10%."

Can you see how this example satisfies the criteria 1. and 3. above? Criteria 2. and 4. would be found in the body of the paper.

As another example, consider the topic of the declining shark population. The following are statements ranking from "no thesis" to "strong" in terms of the definition above:

- **No thesis:** There are reasons why shark populations are in decline.
- **Mild:** Overfishing of sharks has led to a world-wide decline in shark population.
- **Mild:** Changing technology and lack of international cooperation may lead to the extinction of sharks.
- **Strong:** Great white shark population in the coastal seas of Australia has decreased by 30% in the last 10 years due to poaching.

This last example can be said to be strongly worded because it specifies i) the type of shark being studies, ii) the location of the study, iii) the amount of change, iv) the period of time over which the change has occurred, and v) the cause of the change.

Sometimes theses are not as "strongly" worded or phrased as above. We therefore need to properly understand the aim of a thesis, and then look to see if the wording, phrasing, language, etc., intends to mean a thesis.

So how can we describe the aim of a thesis in broader and more fundamental terms? Maybe as follows: Most generally, a thesis says that

something happens (or has happened),
under certain conditions or in a certain environment,
and this thing can be tested or has been tested (where testing implies method/methodology).

This broad description of the aim of a thesis will be useful when analysing the examples to come.

Examples

Let us consider the following seven texts and see what their theses are. The topic of these texts are

- Text 1: Mathematics: Ordinary differential equations;
- Text 2: Operational research/Management science;
- Text 3: Business analytics;
- Text 4: Software engineering;
- Text 5: Mechanical Engineering: Elasticity of beams;
- Text 6: Mechanical engineering: Simulation of robot arms;
- Text 7: Mathematics Education.

Text 1: Mathematics: Ordinary differential equations

In this paper we study the reduction of 3rd order ordinary differential equation to a system of 1st order ordinary differential equation via the X transformation. Under suitable condition of boundedness and convergence we prove that such a reduced system is solved more efficiently (i.e. in a polynomial time) compared to standard methods.

Analysis

Topic sentence: aim of the paper.	In this paper we study the reduction of 3rd order ordinary differential equation to a system of 1st order ordinary differential equation

Method: Specific method.	via the X transformation.
Specifying assumptions, conditions or constraints	under suitable condition of boundedness and convergence
Thesis (here, a theorem)	we prove that such a reduced system is solved more efficiently (i.e. in a polynomial time) compared to standard methods

Text 2: Operational research/Management science

A critical path scheduling problem, called a "divisible activity" model, is investigated in which a single activity can have its completion time divided up and allocated to different 'locations' along the project path. A new algorithm for determining the allocation of such a "divisible activity" model is given, with the aim of minimizing total project time. Although the algorithm is very similar to those used in network-flow type problems, the final results are shown to improve efficiency of the overall running of the project.

Analysis

Topic sentence: Statement of the specific type of critical path problem to be studies.	A critical path scheduling problem, called a "divisible activity" model, is investigated
Methodology/approach: Description of the method to be considered.	in which a single activity can have its completion time divided up and allocated to different 'locations' along the project path.
Original contribution to knowledge: The creation of a new algorithm.	A new algorithm for determining the allocation of such a "divisible activity" model is given,
Thesis: This could form part of a thesis	with the aim of minimizing total project time.
Comparison with similar algorithms.	Although the algorithm is very similar to those used in network-flow type problems,
Thesis: This could form part of the thesis.	the final results are shown to improve efficiency of the overall running of the project.

Taking the two thesis parts together we could make a *strong thesis statement* to be

> "We create a new algorithm for determining the allocation of "divisible activities" which minimizes total project time and improves efficiency of the overall running of the project."

Text 3: Business analytics

Organisations utilise social media technologies for various customer engagement and external-facing activities in recent years. This research examines the extent to which the business strategies and social media strategies of organisations are aligned. Using a sample of 33 organisations competing in the information technology industry, the business strategies were operationalised using data extracted from the annual 10-K reports while the social media strategies were identified from the Twitter feeds. Topic modelling with latent semantic analysis revealed six different orientations in the business and social media strategies of organisations, which were used to evaluate alignment. This study also identified clusters of organisations with varying levels of alignment. Implications for research and practice are discussed.

"Alignment of business and social media strategies: insights from a text mining analysis",
Amir Hassan Zadeh & Anand Jeyaraj,
Journal of Business Analytics, Volume 1, 2018 - Issue 2

Analysis

Topic sentence (acts as general information).	Organisations utilise social media technologies for various customer engagement and external-facing activities in recent …
Aim of the paper.	This research examines the extent to which the business strategies and social media strategies of organisations are aligned.
Methodology.	Using a sample of 33 organisations competing in the information technology industry, the business strategies were operationalised using data extracted from the annual 10-K reports while the social media strategies were identified from the Twitter feeds. Topic modelling with latent semantic analysis revealed six different orientations in the business and social media strategies of organisations, which were used to evaluate alignment.
Part of the aim of the paper: a sub-aim	This study also identified clusters of organisations with varying levels of alignment.
Thesis	No "hard/strongly" worded thesis.

Text 4: Software engineering

A formal, general model of program dependences is presented and used to evaluate several dependence-based software testing, debugging, and maintenance techniques. Two generalizations of control and data flow dependence, called weak and strong syntactic dependence, are introduced and related to a concept called semantic dependence. Semantic dependence models the ability of a program statement to affect the execution behavior of other statements. It is shown, among other things, that weak syntactic dependence is a necessary but not sufficient condition for semantic dependence and that strong syntactic dependence is a necessary but not sufficient condition for a restricted form of semantic dependence that is finitely demonstrated. These results are then used to support some proposed uses of program dependences, to controvert others, and to suggest new uses.

"A Formal Model of Program Dependences and Its Implications for Software Testing, Debugging, and Maintenance", Andy Podgurski And Lori A. Clarke, IEEE Transactions On Software Engineering. Vol. 16. No. 9, September 1990.

Analysis

Topic sentence and aim of the paper.	A formal, general model of program dependences is presented and used to evaluate several dependence-based software testing, debugging, and maintenance techniques.
Developing the idea of the topic sentence: three examples.	Two generalizations of control and data flow dependence, called weak and strong syntactic dependence, are introduced and related to a concept called semantic dependence. Semantic dependence models the ability of a program statement to affect the execution behavior of other statements.
Applications.	These results are then used to support some proposed uses of program dependences, to controvert others, and to suggest new uses.
Thesis.	It is shown, among other things, that weak syntactic dependence is a necessary but not sufficient condition for semantic dependence and that strong syntactic dependence is a necessary but not sufficient condition for a restricted form of semantic dependence that is finitely demonstrated.

Text 5: Mechanical Engineering: Elasticity of beams

This article presents an alternate final solution to the deflection profile of a simply supported beam under sinusoidal load based on the theory of elasticity. It begins with a review of the same problem found in typical graduate textbooks, which ends with an elasticity solution that is valid only for moderately thick beams, and thereafter provides an alternative ending for providing a more accurate deflection profile that is valid for very thick beams. Plotted results show evidence on the deficiency of the textbook solution for very thick beams, thereby limiting its use as a verifier for the Mechanics of Materials solution. Unlike the existing simplified elasticity model, the exact model does not reduce to the Mechanics of Materials model when the Poisson's ratio of the beam material is −1. In addition to being a better verifier to the Mechanics of Materials solution, the proposed exact elasticity solution can be easily reduced to the simplified elasticity solution that is currently adopted in some graduate textbooks.

"Revisiting the elasticity solution for a simply supported beam under sinusoidal load.",
Teik-Cheng Lim, International Journal of Mechanical Engineering Education, 2018, Vol. 46(1), 41–49.

Analysis

Topic sentence.	This article presents an alternate final solution to the deflection profile of a simply supported beam under sinusoidal load based on the theory of elasticity.
Summary of current approaches	It begins with a review of the same problem found in typical graduate textbooks, which ends with an elasticity solution that is valid only for moderately thick beams, and thereafter provides an alternative ending for providing a more accurate deflection profile that is valid for very thick beams.
Identifying problems in current approaches.	Plotted results show evidence on the deficiency of the textbook solution for very thick beams, thereby limiting its use as a verifier for the Mechanics of Materials solution.
Thesis (but not strongly worded as such): The solution corrects the above problem.	Unlike the existing simplified elasticity model, the exact model does not reduce to the Mechanics of Materials model when the Poisson's ratio of the beam material is −1. In addition to being a better verifier to the Mechanics of Materials solution, the proposed exact elasticity solution can be easily reduced to the simplified elasticity solution that is currently adopted in some graduate textbooks.

Text 6: Mechanical engineering: Simulation of robot arms

A complete mathematical model of SCARA robot (Serpent 1) is developed including servo actuator dynamics and presented together with dynamic simulation in this paper. The equations of motion are derived by using Lagrangian mechanics. Dc servo motors driving each robot joint is studied with PD controller action. Serpent 1 robot is instructed to achieve pick and place operations of three different size cylindrical objects through assigned holes. The performance of robot-actuator-control system is examined with numerical simulation and experimentally verified. The results of experimentation are given with comments. An agreement between the model and the experiments is certainly obtained herein.

"Mathematical modelling, simulation and experimental verification of a SCARA robot",
M. Taylan Das, L. Canan Dulger, Simulation Modelling Practice and Theory 13 (2005) 257–271.

Analysis

Topic sentence which also describes the aim of the paper.	A complete mathematical model of SCARA robot (Serpent 1) is developed including servo actuator dynamics and presented together with dynamic simulation in this paper.
Mathematical/experimental method used.	The equations of motion are derived by using Lagrangian mechanics. Dc servo motors driving each robot joint is studied with PD controller action. Serpent 1 robot is instructed to achieve pick and place operations of three different size cylindrical objects through assigned holes. The performance of robot-actuator-control system is examined with numerical simulation and experimentally verified.
Thesis	None, but it looks like "An agreement between the model and the experiments is certainly obtained herein." Could be turned into a thesis? How so?

Text 7: Mathematics Education

Knowing an equation has a unique solution is important from both a modelling and theoretical point of view. For over 70 years, the approach to learning and teaching 'well-posedness' of initial value problems (IVPs) for second- and higher-order ordinary differential equations has involved transforming the problem and its analysis to a first-order system of equations. We show that this excursion is unnecessary and present a direct approach regarding second- and higher-order problems that does not require an understanding of systems.

"Rethinking pedagogy for second-order differential equations: a simplified approach to understanding well-posed problems", Christopher C. Tisdell, *Journal of Mathematical Education in Science and Technology*, 2017, 48:5, 794-801.

Analysis

Topic sentence, stating the importance of an aspect of maths.	Knowing an equation has a unique solution is important from both a modelling and theoretical point of view.
Some history about how the general maths topic has been taught in the past.	For over 70 years, the approach to learning and teaching 'well-posedness' of initial value problems (IVPs) for second- and higher-order ordinary differential equations …
Specific approach used in the past.	… has involved transforming the problem and its analysis to a first-order system of equations.
Statement against the past method.	We show that this excursion is unnecessary …
Thesis.	… and present a direct approach regarding second- and higher-order problems that does not require an understanding of systems.

Exercises

Consider the texts below. Can you identify a thesis in each of these?

Abstract 1: Statistics education

This paper presents a survey of the reported research about students' errors, difficulties and conceptions concerning elementary statistical concepts. Information related to the learning processes is essential to curricular design in this branch of mathematics. In particular, the identification of errors and difficulties which students display is needed in order to organize statistical training programmes and to prepare didactical situations which allow the students to overcome their cognitive obstacles. This paper does not attempt to report on probability concepts, an area which has received much attention, but concentrates on other statistical concepts, which have received little attention hitherto.

"Errors and difficulties in understanding elementary statistical concepts", C. Batanero et al., *International Journal of Mathematical Education in Science and Technology*, 25:4, 527-547.

Abstract 2: Mathematics education (differential equations)

A study of first-year undergraduate students' interpretational difficulties with first-order ordinary differential equations (ODEs) in modelling contexts was conducted using a diagnostic quiz, exam questions and follow-up interviews. These investigations indicate that when thinking about such ODEs, many students muddle thinking about the function that gives the quantity to be determined and the equation for the quantity's rate of change, and at least some seem unaware of the need for unit consistency in the terms of an ODE. It appears that shifting from amount-type thinking to rates-of-change-type thinking is difficult for many students. Suggestions for pedagogical change based on our results are made.

"Student interpretations of the terms in first-order ordinary differential equations in modelling contexts", David R. Rowland & Zlatko Jovanoski, *International Journal of Mathematical Education in Science and Technology*, 35:4, 503-516.

Abstract 3: Statistics research

In this article, we propose an outlier detection approach in a multiple regression model using the properties of a difference-based variance estimator. This type of a difference-based variance estimator was originally used to estimate error variance in a non-parametric regression model without estimating a non-parametric function. This article first employed a difference-based error variance estimator to study the outlier detection problem in a multiple

regression model. Our approach uses the leave-one-out type method based on difference-based error variance. The existing outlier detection approaches using the leave-one-out approach are highly affected by other outliers, while ours is not because our approach does not use the regression coefficient estimator. We compared our approach with several existing methods using a simulation study, suggesting the outperformance of our approach. The advantages of our approach are demonstrated using a real data application. Our approach can be extended to the non-parametric regression model for outlier detection.

"Outlier detection using difference-based variance estimators in multiple regression",
Chun Gun Park & Inyoung Kim,
Communications in Statistics - Theory and Methods, Volume 47, 2018 - Issue 24.

Abstract 4: Mathematics education (teacher education)

The purpose of this exploratory study was to develop a model to examine teachers' instructional practice in secondary school mathematics in relationship underlying cognitions. The instructional practice and cognitions of seven experienced seven beginning teachers of secondary school mathematics were examined as a basis the creation of the model. To examine instructional practice a Phase-Dimension Framework for the Examination of Mathematics Teaching was developed. Data were obtained observations, lesson plans, videotapes and audiotapes of structured interviews course of one semester. The value of the model lies in its usefulness as a guide for teachers to reflect on their instructional practice and underlying cognitions in a structured, comprehensive manner.

"A Cognitive Model for Examining Teachers' Instructional Practice in Mathematics: A Guide for Facilitating Teacher Reflection", Alice F. Artzt and Eleanor Armour-Thomas, *Educational Studies in Mathematics*, Dec., 1999, Vol. 40, No. 3 (Dec., 1999), pp. 211-235.

Exercise

Choose a paper of your own and identify the author's thesis. What is s/he claiming? What is it that s/he is saying will work, or will work better than, or is an improvement on, or is more efficient, etc.?

The language/discourse of a thesis

The aim of the examples above is to show you the *underlying principle* of what makes a *thesis*. This underlying principle is what you should aim to learn and understand. Then you will know *how* to write a thesis. The underlying principle illustrates a certain style of writing or phrasing which distinguishes a thesis from other types of writing.

There are two factors (at least) which make a thesis statement:

- particular vocabulary: the vocabulary of a topic + action words (verbs);
- the way in which the statement is phrased in-and-of-itself, as well as how this statement follows on from the preceding text. In other words, the text preceding a statement acts as context and can influence whether or not that statement is a thesis statement.

Text 1: Language analysis

"… we prove that such a reduced system is solved more efficiently (i.e. in a polynomial time) compared to standard methods."

Text 2: Language analysis

"… the final results are shown to improve efficiency of the overall running of the project."

Text 7: Language analysis

"… present a direct approach regarding second- and higher-order problems that does not require an understanding of systems."

Note that thesis statements can be written in very different styles depending on the discipline you are working in. Scientific disciplines usually make more categorical, definitive thesis statements such as "We will show that … is more efficient by 10%", or "We improve channel capacity by using … The resulting improvement is of the order of 10%", or "This new design minimises deviation such that …"

In mathematics, there is no such things as a thesis in the way we are discussing it here. There are only theorems. And theorems are always followed by proofs of the correctness of the theorem. In this case there is no debate or argument about a theorem. It is a fact, proven to be so.

For example,

- The fundamental theorem of arithmetic says that any integer can be factored into prime powers, e.g. $60 = 2^2 \times 3 \times 5$. This theorem is always true.
- The fundamental theorem of algebra says that any polynomial can be factorised into complex factors, e.g. $x^3 + x^2 + x + 1 = (x + i)(x - i)(x + 1)$. This theorem is always true.
- The fundamental theorem of calculus says that integration is the reverse of differentiation, and that the value of the definite integral is equal to the antiderivative evaluated at the boundaries of the interval of integration. Under certain conditions, this theorem is always true.

What of mathematics? (Optional)

Given what we have seen so far, there is no such thing as a thesis or hypothesis in mathematics. There are only theorems. In mathematics the four criteria above of i) the making of a statement, ii) the studiability of the statement, iii) the evidence which proves the statement, and iv) the fact that we can argue in favour of the statement on the basis of the evidence, all fall under one and the same category: theorem and proof. Theorems are true statements, and proofs are the demonstration of the truth of those statements.

For example,

Theorem

If n and m are odd integers, then $n + m$ is even.

Proof: Let n and m be odd integers. Then

$$n = 2j + 1 \qquad \text{and} \qquad m = 2k + 1$$

for some integers j and k. Then

$$\begin{aligned} n + m &= (2j + 1) + (2k + 1) \\ &= 2j + 2k + 2 \\ &= 2(j + k + 1). \qquad (*) \end{aligned}$$

Since $j + k + 1$ is integer, and (*) is by definition even, $n + m$ is even. Q.E.D

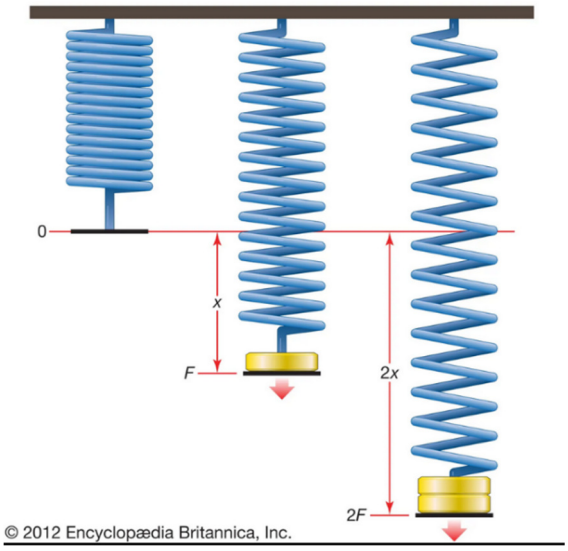
So, there is no such thing as an untrue theorem, and there is no such thing as a theorem being a hypothesis. Any mathematical statement which has yet to be proved is called a conjecture.

Research question and thesis statement

In general all that is required for the physical sciences is a thesis/hypothesis, i.e. one single sentence making a claim to truth. For the IPM you need also to develop a *thesis statement*. This is simply a short elaboration of the thesis.

Along with the thesis statement you will need to write a research question, i.e. a question for which you seek an answer or a response. The point of your extended essay will then be to answer this research question using literature as your source of evidence in order to confirm your thesis.

To see what a research question and thesis statement looks like we will a text from Barry Gilbert and Peter Glanz (1983): "Springs: Distorted and combined", *Physics Teacher*, **21**, 430–434. This text refers to Hooke's law. To understand this text recall that Hooke's law states that if a force is applied to the end of an unstretched spring of length l the stretch/extension of the spring is proportional to the amount of force. In this situation the force is created by adding a weight to the end of the spring as illustrated in the diagram below.



An illustration of Hooke's law

Hooke's law only applies as long as the spring is not stretched so far as to permanently deform it.

Gilbert and Glanz's text is as follows:

> "Suppose you have a standard laboratory spring that has a section which has been permanently distorted […]. How has the spring constant changed? Can one even say that there is a spring *constant*? If the "bad" part were snipped out, how would the new spring constant compare to the original? Does the distorted section of the spring still obey a linear Hooke's law relation with a unique spring constant throughout its elastic range? If a partially distorted spring can be considered can be considered two springs connected together, does the combination have one unique spring constant?"

This paragraph presents many research questions. The first two questions are broad questions (which might actually be termed "topic questions") made more specific by the other questions:

- How has the spring constant changed? Can one even say that there is a spring *constant*?
  - If the "bad" part were snipped out, how would the new spring constant compare to the original?
  - Does the distorted section of the spring still obey a linear Hooke's law relation with a unique spring constant throughout its elastic range?
  - If a partially distorted spring can be considered can be considered two springs connected together, does the combination have one unique spring constant?

The remaining three questions can be transformed into strong hypotheses. For example:

1a. *Original question*: "If the "bad" part were snipped out, how would the new spring constant compare to the original?"

1b. *Strong hypothesis*: "Removing the permanently distorted section of the spring increases the value of the spring constant by a factor equal to the length of the removed part."

2a. *Original question*: "Does the distorted section of the spring still obey a linear Hooke's law relation with a unique spring constant throughout its elastic range?"

2b. *Strong hypothesis*: "When the spring is permanently distorted the value of the spring constant follows the non-linear elasticity equations".

Referring to the students in their class, Gilbert and Glanz then continue later on as follows:

> "A survey of our class produced the almost unanimous consensus that the spring constant of any spring is dependent only on the metal used in construction and the way the coils are wound, i.e. tightly or loosely. Thus, they predict the same [value for the spring constant] for both cutting and combining springs. Textbook discussions were used […] to substantiate this intuitive conclusion."

This paragraph can be classified as a thesis statement because it contains two things:

- a hypothesis, which can be paraphrased as "the spring constant of any spring is dependent on the metal used in construction and the way the coils are wound",
- a thesis statement, illustrated by the paragraph as a whole. Here we find additional comments made in relation to the hypothesis:
    - *experimental outcomes/results*: "A survey of our class produced",
    - *future outcomes/predictions*: "Thus, they predict",
    - *evidence in support of outcomes*: "Textbook discussions were used to substantiate".

One can therefore summarise the thesis statement as follows:

Thesis statement = hypothesis + additional comments made in relation to the hypothesis.

Such additional comments can include problems, consequences, positive outcomes/results, applications, etc. of the hypothesis.

Example 1

The following text comes from Delourme, B. et. al. (2021): "A stable, unified model for resonant Faraday cages", *Proceedings of the Royal Society A*, **477**:20200668

> "We study some effective transmission conditions able to reproduce the effect of a periodic array of Dirichlet wires on wave propagation, in particular when the array delimits an acoustic Faraday cage able to resonate. In the study of Hewett & Hewitt (2016 *Proc. R. Soc. A* **472**, 20160062 (doi:10.1098/rspa.2016.0062)) different transmission conditions emerge from the asymptotic analysis whose validity depends on the frequency, specifically the distance to a resonance frequency of the cage. In practice, dealing with such conditions is difficult, especially if the problem

is set in the time domain. In the present study, we demonstrate the validity of a simpler *unified* model derived in Marigo & Maurel (2016 *Proc. R. Soc. A* **472**, 20160068 (doi:10.1098/rspa.2016.0068)), where *unified* means valid whatever the distance to the resonance frequencies. The effectiveness of the model is discussed in the harmonic regime owing to explicit solutions. It is also exemplified in the time domain, where a formulation guaranteeing the stability of the numerical scheme has been implemented."

The hypothesis is suggested by lines 8-9: "In the present study, we demonstrate the validity of a simpler *unified* model derived in Marigo & Maurel". This can be rewritten in a "stronger/harder" style as "In the present study, we develop a unified model (derived from Marigo & Maurel) which is simpler than …". The subsequent lines of 11-14 form part of a thesis statement.

Example 2

The following text comes from Amiri, S., et. al. (2023): "Rayleigh wave group velocities in North-West Iran: SOLA Backus-Gilbert vs. Fast Marching tomographic methods", *Seismica*, *2*(2):

"In this study, we focus on Northwest Iran and exploit a dataset of Rayleigh-wave group-velocity measurements obtained from ambient noise cross-correlations and earthquakes.

We build group-velocity maps using the recently developed SOLA Backus-Gilbert linear tomographic scheme as well as the more traditional Fast-marching Surface-wave Tomography method. The SOLA approach produces robust, unbiased local averages of group velocities with detailed information on their local resolution and uncertainty; however, it does not as yet allow ray-path updates in the inversion process. The Fast-marching method, on the other hand, does allow ray-path updates, although it does not provide information on the resolution and uncertainties of the resulting models (at least not without great computational cost) and may suffer from bias due to model regularisation.

The core of this work consists in comparing these two tomographic methods, in particular how they perform in the case of strong vs. weak seismic-velocity contrasts and good vs. poor data coverage.

16 We demonstrate that the only case in which the Fast-marching inversion
17 outperforms the SOLA inversion is for strong anomaly contrasts in regions with
18 good path coverage; in all other configurations, the SOLA inversion produces more
19 coherent anomalies with fewer artefacts."

The thesis statement is covered by the whole of the paragraph of lines 13–19. The hypothesis itself is suggested by lines 16–18, "We demonstrate that the only case in which the Fast-marching inversion outperforms the SOLA inversion is for strong anomaly contrasts in regions with good path coverage". Note that this hypothesis could also have been written in the form "The Fast-marching inversion outperforms the SOLA inversion only in the case of strong anomaly contrasts in regions with good path coverage."

Example 3

The following text comes from Nikolajsen JL (2014), "New stopping criteria for iterative root finding", *Royal Society Openscience,* 1: 140206.

1 "A set of simple stopping criteria is presented, which improve the efficiency of
2 iterative root finding by terminating the iterations immediately when no further
3 improvement of the roots is possible. The criteria use only the function evaluations
4 already needed by the root finding procedure to which they are applied. The
5 improved efficiency is achieved by formulating the stopping criteria in terms of
6 fractional significant digits. Test results show that the new stopping criteria reduce
7 the iteration work load by about one-third compared with the most efficient
8 stopping criteria currently available. This is achieved without compromising the
9 accuracy of the extracted roots."

This is a text from a mathematics paper so according to the strict usage of mathematical terminology there is no such thing as a hypothesis here. There would only be a theorem and a proof. However, if there were a hypothesis it would be suggested by lines 6–8: "Test results show that the new stopping criteria reduce the iteration work load by about one-third compared with the most efficient stopping criteria currently available". This can be rewritten in a "stronger" style as "The new stopping criteria X reduce the iteration work load by about one-third compared with the most efficient stopping criteria currently available". The thesis statement is covered by the whole of the paragraph itself, i.e. lines 1–9.

Example from previous STEM students

Examples of thesis statements from past C3 STEM students include the following. One of these is very short. Also, I have edited these for readability and grammar so that they read well:

1) "According to WHO (2015) the cost of sequencing a human gene has dropped from $100 million in 2001 to about $5000 in 2015. In this essay I will show that because the cost of new technology has reduced so much it has made gene therapy cheaper." (too general)
2) "Previous studies have identified several types of methods for measuring the conductivity of mobile communication technology. This gives researchers opportunities to choose particular methods for specific situations. I will argue that NSMM should be chosen to measure conductivity in 5G communication technology due to the fact that it gives the best accuracy".
3) "Recent studies illustrate that the main reason for buildings collapsing during WC earthquakes is not because of the low standard codes or construction process but mostly because of the unqualified structural material. In this essay I will show that what kind of materials are qualified for buildings".
4) "Previous work on passive houses has shown that they are suitable for most cold weather areas. In this essay I will show that using insulation and active ventilation equipment allows passive houses to be developed for hot weather areas".

Three other examples of research questions and thesis statements from past IPM students can be found in the separate document uploaded to MS Teams (in the usual place).

Does your thesis and thesis statement pass the "how and why?" test?

If a reader's first response is "how?" or "why?", your thesis may be too open-ended and lack guidance for the reader. See what you can add to give the reader a better take on your position right from the beginning."

Finally, note that your extended essay has to address your thesis directly and specifically. In other words, you need to answer your claim/question using the evidence you have collected in order to support your thesis statement.

How do you develop a thesis/statement?

A strong thesis has to be a very precise statement. But when we are starting a new line of research we do not tend to think about our topic to such a precise degree. What actually happens is that a thesis tends to come at the end of a time of reading around your topic, mulling it over, having insights, talking to other people, reading further into your topic, carrying out simplified experiments (if relevant), mulling over the results, having more insights, brainstorming with other people, etc… and not necessarily in this order. In other words, a thesis statement can come at the end of what might be called a mini research cycle, after which we are able to design our experiment very specifically in order to collect the most relevant and reliable data which will provide evidence in support of our thesis.

If all else fails

If you don't know how to write a thesis statement, then it means that you haven't yet personally connected with a topic and with a particular studiable aspect or phenomenon of that topic. Someone who really knows what s/he wants to talk about, what s/he wants to say will always be able to create a sentence or two which is a thesis statement. You need to get to this point. You need to get to the place of wanting to say something, of wanting to claim that something is true or valid or viable. If you still have not got to this place then you will need to read more widely (or try out test experiments or activities which allow you to collect data) in order to find something, anything which triggers you into wanting to investigate something particular. Once you get to this point write your idea down, then refine your writing so that it ultimately becomes a thesis statement.