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An Experience Mapping Method for Delayed Understanding in STEM Education

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ABSTRACT [1]

This study introduces a novel experience-mapping methodology designed to alleviate the challenge of delayed comprehension in education. Education often entails a delayed understanding of its content and value. This comprehension lag often results in discrepancies between learners and educational content, potentially leading to setbacks in the learning process. In response, we present a mapping model that delineates the essential structure of educational content and positioning between the learner and the content. This model serves as a guiding roadmap, enabling learners to navigate the complexities of educational content through a pair of constructed semantic networks. These networks reflect insights from recent brain science and educational experience studies. This study delves into the application of the STEM (Science, Technology, Engineering, Mathematics) education. Furthermore, we discuss the potential of experience mapping within the spheres of curriculum design and faculty development. Through these applications, this research contributes to the development of educational.

Keywords: Experience Mapping, Comprehension Lag, STEM, Syllabus Design, Faculty Development.

1. INTRODUCTION

There is often a time lag in education during which learners fully grasp the value and structure of educational content [24]. In academia, students often achieve a thorough understanding of a topic long after finishing their course. For example, Bourbaki warned readers in the preface of his famous textbooks "*Elements of Mathematics*" that "*... It follows that the utility of certain considerations will not be immediately apparent to the reader unless he has already a fairly extended knowledge of mathematics; otherwise he must have the patience to suspend judgment until the occasion arises*."[2] Furthermore, such comprehension may be delayed until subsequent subjects, as in the case of linear algebra, which is often understood during later courses such as dynamical systems or quantum mechanics. Education is considered a service with a "comprehension lag". This is a form of delayed utility [18].

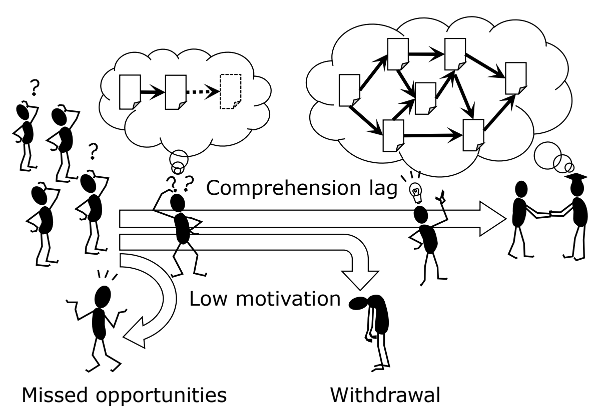

Figure 1. Comprehension lag causes opportunity loss, low motivation, and fall out.

A comprehension lag may lead to mismatches in the delivery of educational services. For instance, gaps in understanding of the structure and value of educational

[a)] This is the affiliation at the time of the first submission.

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content between providers and learners can result in missed opportunities, low motivation, and withdrawal during the course. In education, many areas require the accumulation of segmented subjects. Consequently, a comprehension lag can lead to a cascade of 'falling out of phase' between and within subjects [24]. **Figure 1** illustrates the problems associated with this type of comprehension lag. Therefore, the solution we need to find is an experience-mapping tool that allows us to share with learners what they need to understand, while also serving as a syllabus design tool.

The paper is structured as follows: Section 2 describes the experience mapping methodology; Section 3 introduces our new experience mapping approach based on brain science findings; Section 4 describes the application of our mapping methodology to STEM (Science, Technology, Engineering, Mathematics) education; Section 5 discusses future work.

2. RELATED WORK ON MAPPING EXPERIENCE AND COGNITION

The aim of this study was to explore a mapping tool used as an experience design tool and to communicate to learners the knowledge structure required to comprehend the subject. This section outlines key customer experience mapping methods, their basic structures, differences, and applications in education and other fields. In addition, we provide an explanation of a cognitive mapping method used to visualize customer understanding.

2.1 Mapping the Customer Experience

Various customer experience mapping methods have been proposed for identifying the value of customer experience and its sharing within an organization [14]. These diagrams, also known as aligned diagrams, include experience maps, customer journey maps, etc. Alignment diagrams facilitate the identification of pain points and touch points. A touch point arises when the customer's behavior and service interact, generating the service value. Conversely, a pain point is a phase where an unsatisfactory customer experience occurs. Alignment diagrams are employed to maintain the consistency of views on the customer experience [13].

Among the types of diagrams typically used, the customer journey map and the experience map represent the customer experience in chronological order by stage [7][14]. Recent research has focused on the use of experience mapping as a visual communication tool for students and faculties in education. A study has applied customer journey maps and experience maps to design the curriculum for a graduate program. It has been reported that these mappings contribute to students graduating on time by creating 'timeline handouts' and allowing for more flexible selection of student specialty areas [12].

However, these mapping methodologies are not specific to services with comprehension lags. When designing educational experiences for individuals with comprehension lags, it is also desirable to provide a map of the knowledge structure that needs to be understood.

2.2 Mind Map and Concept Map

Semantic networks are widely used for method for visualizing conceptual understanding. These networks represent knowledge with nodes and the relationships between these nodes as edges. In the field of education, semantic networks represent the depth of understanding. A famous experiment to categorize similar but different physics problems has shown that the difference between experts and novices is reflected in the difference in the semantic networks they draw [4].

Mind maps and concept maps are common ways of expressing understanding through semantic networks. A mind map presents a visual representation of a collection of ideas linked by mutual associations. Its purpose is to discover creative relationships between ideas [3]. Conversely, a concept map associates several concepts through precise relationships between them. Compared with mind maps, concept maps represent layered structures of concepts [19]. (See **Figure 2**.)

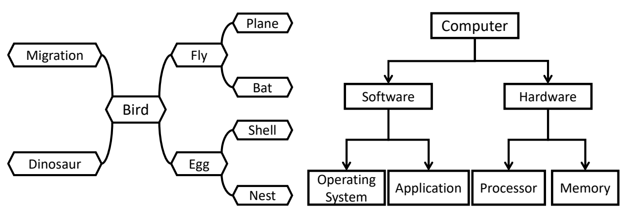


Figure 2. Mind mapping (left) creatively discovers relationships between ideas. Concept mapping (right) organizes the structure between ideas.

Both mind maps and concept maps serve as teaching tools in education and are also used to assess understanding. For example, concept mapping has been employed to illustrate a inconsistency between a teacher's complex network structure of concepts and a student's straight shaped network of the concept due to the lecture's 'linear story' [15]. Prior use of concept maps has been reported to increase meaningful learning and significantly improve the quality of university teaching [11]. These effects of the semantic network motivate us to explore an experience design tool to improve comprehension lag.

2.3 Beyond Concept Mapping

Mind maps and concept maps are commonly employed to illustrate knowledge networks however, additional insights from other areas can be used to improve them. The field of brain science, which is progressing remarkably at the moment has provided many insights into spatial cognition. Urban design has traditionally been a strong area for mapping. In the following section we discuss the use of brain science and urban design knowledge in map making.

3. METHODOLOGIES

As previously discussed, comprehension lags in education could lead to missed learning opportunities, low motivation, and falling out during courses [24]. In contrast, it contributes to improving the quality of education and on-time graduation if teachers and students share the structure of educational content and experiences before learning a subject [12]. Therefore, it is advantageous to employ visual aids to present the educational content structure in educational experience design to enhance comprehension and navigation for the learner's experience journey.

To support our approach, we use the analogy of mountain guiding. For novice mountaineers, it can be challenging to grasp the holistic experience of climbing (comprehension lag). In such situations, the guide will share with the climber a map of the entire mountain landscape, landmarks, and climbing routes. Such a map is not an experience in itself. Instead, it serves as a model for reducing the cognitive gap caused by comprehension lag. (See **Figure 3**.)

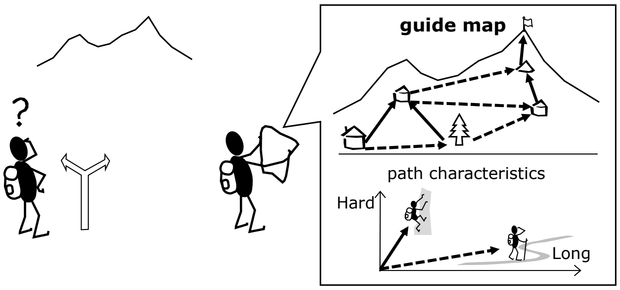


Figure 3. By providing a perspective of routes and characteristics of paths, a guide map mitigates beginners' comprehension lag.

3.1 Three Key Methodologies

In developing our approach to the experience route map, we considered three key factors. First, we have drawn upon the insights of brain science on cognition. Second, we have included legibility as a crucial aspect of the route map and, third, we have employed a measure of the level of experience.

3.1.1 Brain science findings: In the experience route map structure, we reference brain science discoveries related to spatial and object recognition. These are the result of the cortical organization's function, which includes specialized cells known as "grid cells" and "place cells" [23]. The grid cells and place cells determine the spatial extent and location and produce human object recognition through the "what" pathway, which describes the shape of an object, and the "where" pathway, which describes where an object is located [22]. These two neural pathways within the human brain use different frames of reference for spatial perception. The "what" pathway employs an allocentric (object-centered) frame of reference attached to the object to recognize the shape of the object. In contrast, the "where" pathway uses an egocentric (subject-centered) frame of reference that originates from us to identify the location of the object [9].

The recognition of abstract concepts by the brain is also believed to be similar to spatial recognition using such a grid-cell frame of reference [5]. In addition, it is proposed that the recognition of linguistic or specialized knowledge and concepts is also similar to spatial recognition using reference frames, based on the structural similarity of the cortical columns involved in spatial and linguistic recognition. As these more complex knowledge and concepts are interconnected and nested, it is a natural analogy that recognition in the "what" pathway would have a network structure [9][10].

Based on brain science findings, we present an experience route map that is a pair of two types of map: the "what" map and the "where" map. Each map has its own frame of reference. The "What" map displays the conceptual elements that need to be comprehended and the layout of the link structure that connects them. The reference frame of the "What" map indicates the position of each conceptual element from specific perspectives. The "where" map indicates the distance from the learner to the conceptual elements in the "what" map. It is natural to define "distance" as "near" when the level of experience with the element is high and "far" when the level of experience with the element is low.

3.1.2 Legibility as a map: Our experience route map serves as a guide for virtual learners and should be comprehensible to prevent them from losing their way. Therefore, we are incorporating features into our route map that enhance spatial recognition as a navigational aid.

While navigation and wayfinding have been investigated in brain science [1], this study introduces the concept of spatial legibility from the perspective of urban design. In the realm of urban design, the legibility of urban geography comprises five factors. These comprise "path", "landmark", "node", "boundary", and "district" [16][17].

We translate these five factors into the parts of our 'what' map. A path represents a transition or relationship between experiences. A landmark is a significant and remarkable experience or a well-known thing related to the experience. A focus (node) is a network node where many paths converge. A boundary (an edge) divides the frame into two distinct regions. A district is a sub-region enclosed by boundaries that shares common features.

3.1.3 Distance: Level of Experiences: Finally, we introduce a sense of distance in our "where" map. The distance between the experience and the learner in the "where" map is indicated by the level of experience. The level of learning experience in education can be used to measure of the level of experience. It is reasonable to assume that a lower experience level signifies greater distance, whereas a higher experience level indicates a shorter distance.

The following classification of learning engagement using levels of learning experience has been proposed in school education: No experience, Mindless routine, Scattered/Incomplete activity, Pleasant routine, Challenging endeavor, and Aesthetic experience [21]. These levels, presented in previous research, will be used for the time being although it is possible to introduce our own scales as needed in practice.

3.2 Experience Route Mapping

Having established the necessary methodologies, we now describe the structure of our experience route mapping. The route map consists of two different maps: "what" and "where" maps. The "what" map displays the elements that make up the learning experience and the links that connect them, located in the frame of reference. The "what" map illustrates the factual relationships between the educational content and the possible ways of experiencing it. In contrast, the "where" map consists of the distances between the learner's virtual image (persona) and the educational content. This explains the subjective psychological distance between the virtual learner and the experiences. We define the necessary terms and then describe the specific structure of these two maps.

3.2.1 Definitions of Terms: Here, we provide definitions of the terms used in our route maps.

Experience element: An individual event, thing, concept, knowledge, etc. that is the unit of experience division in a route map. It is also called an element or a node.

Link: A connection between two elements is indicated by a link that specifies their relationship as before/after, causal, derived, similar, or correspondent. Directed and undirected links are used according to the nature of the relationship.

Reference frame: A coordinate system that indicates the direction and position of the elements. It can also be referred to as a frame.

An experience route is a feasible pathway through a series of elements as part of the learning experience. It can either progress through links or transition between elements without links. It is simply called a route.

Boundary: A dividing line within the reference frame that separates elements by differences in their properties.

District: A region confined by boundaries within a frame, the properties of which the elements inside and outside of which are different.

Focus: An element on which many links or routes converge.

Landmark. An eminent object or area known for its significance within the frame of reference.

Persona: A hypothetical student has both external attributes as an individual, and internal desires, preferences, and frustrations: an experience level may be set between a persona and elements and districts.

Experience level: Strength of the psychological involvement of a learner with an element or district. Learning experience levels, or levels that are independently defined, can be applied.

3.2.2 Composition of the "what" map: Here, we show the composition of the "what" map. The "what" map is drawn on a reference frame that contains the experience elements to be described. The reference frame is chosen to represent the properties that allow the elements to be well organized. Within this frame, some boundaries are set according to the nature of the frame so that the elements are appropriately divided. These boundaries define the districts. The existence and individual areas of a district can be highlighted individually as required. Elements and, if necessary, landmarks are placed in appropriate locations within the frame or within these districts. Depending on the relationship between the elements, they are connected by links. Different types of links are discriminated against, if necessary. An experience route is added along the learning experience with an arrow that is different from the links.

The ideal type of our "what" map is shown in **Figure 4**.

Our "what" map is a semantic network, but it also has the properties of a geographical route map. We integrate these two aspects by using the parts for legibility, placing the whole map on the reference frame, and relating the boundaries to the frame.

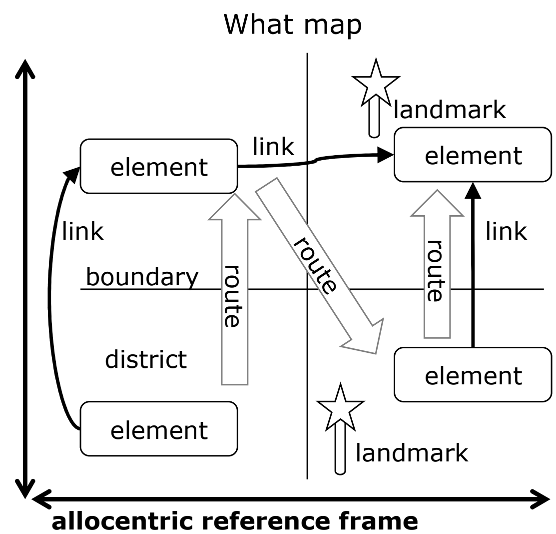


Figure 4. In an ideal type of "what" map, elements are placed on a frame of reference and linked to each other. They are characterized by landmarks, boundaries, and districts.

In addition, note where the route of the experience jumps between unlinked elements. Such jumps may lead transitional volatility making the customer feel lost in the experience space [6]. A problem from the "linear story" understanding [15] as we mentioned at section 2.2. is also likely to occur in such jumps. Our "what" map makes it easier to find this transitional volatility by visualizing the jumps. This is a benefit of extending the semantic network as a route map.

3.2.3 Composition of the "where" map: Next, we describe the composition of the "where" map, which is the other major component of our route map. The "where" map shows the subjective distance between the personas and the elements that make up the experience.

Place the personas that describe personal information related to the experience. Select the elements that are essential to the route of the experience. Describe the experience level for each key element according to the persona's state, and place the elements on the distance map according to the level. If necessary, use a persona-centered reference frame.

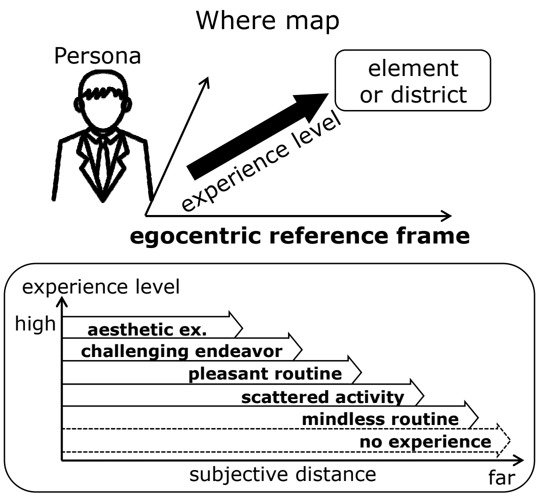


Figure 5. The ideal type of "where" map shows the learner's persona and the distance to the learning elements or their districts on the learner's egocentric frame.

The ideal type of our "where" map is shown in **Figure 5**. Our "where" map represents a link between the learner's persona and the experience elements in the "what" map. Personas are also used in the customer journey map to provide a clearer picture of the learner. Our "where" map also connects the customer journey map to the "what" map through the persona.

3.3 Experience Route Mapping and Concept Mapping

We have constructed Experience Route Maps ("what" and "where" maps) using knowledge from brain science and urban design. The relationship between the Experience Route Map and the Mind Map or Concept Map is shown in **Table 1**.

Table 1. Relationship between the experience route map and the mind map or concept map

	Mind Map	Concept Map	Experience Route Map	
			What Map	Where Map
semantic network	✓	✓	✓	
concept structure		✓	✓	
reference frame			✓	✓
experience level				✓

A mind map consists only of a semantic network, whileas a concept map consists of a semantic network and a conceptual structure. In contrast, in the Experience Route Map, the "what" map has cognitive frames of reference in addition to the semantic network and conceptual structure. The "where" map also shows reference frames and levels of experience. The Experience Route Map is more than a simple extension of the Mind Map or Concept Map.

4. APPLICATION FOR STEM EDUCATION

In this section, we use STEM education as a case study to illustrate the specific form of the two components of our experiential route map: the "what" map and the "where" map. STEM education requires an understanding of the complex relationships among the various concepts within individual subject areas. STEM education is an appropriate application for our route map.

4.1 Case 1: Euler's Theorem

Here we will use a simple math topic to illustrate our route map for students in high school or at the beginning of college. Euler's formula states that exponential and trigonometric functions are equivalent to complex functions. As real functions, exponential and trigonometric functions are apparently different, but they have corresponding structures. Here, we show a mapping based on the Maclaurin expansion that makes it easy to determine the correspondence.

Figure 6 shows a "what" map for this topic. The "what" map represents not only the derivation process of the equivalence of trigonometric and exponential functions as complex functions (solid arrows) but also the implicit correspondence between trigonometric and exponential functions as real-valued functions (dashed lines). The "what" map visualizes these implicit relationships that are typically overlooked in knowledge transfer.

As mentioned in Section 3.2.2, students are likely to feel lost where the route jumps between unlinked elements. Visualizing the jumps in the "what" map makes it easier to find the points at which such "additional comprehension lag" happens.

The "where" map shows the distance between the elements of the topic and the target student. These distances provide clues for designing touch points in the teaching phase.

An example of a "where" map is shown in **Figure 7**. The attributes and attitudes of the persona (Andy) are similarly described in the customer journey map. The "where" map also includes learning experience levels based on trigonometric and exponential functions as learning elements. These levels represent the distance between the student and the learning element, which is reflected in the route setting on the "what" map. For example, Andy starts with trigonometric functions at a higher level, but he needs to be careful when jumping from trigonometric functions to exponential functions.

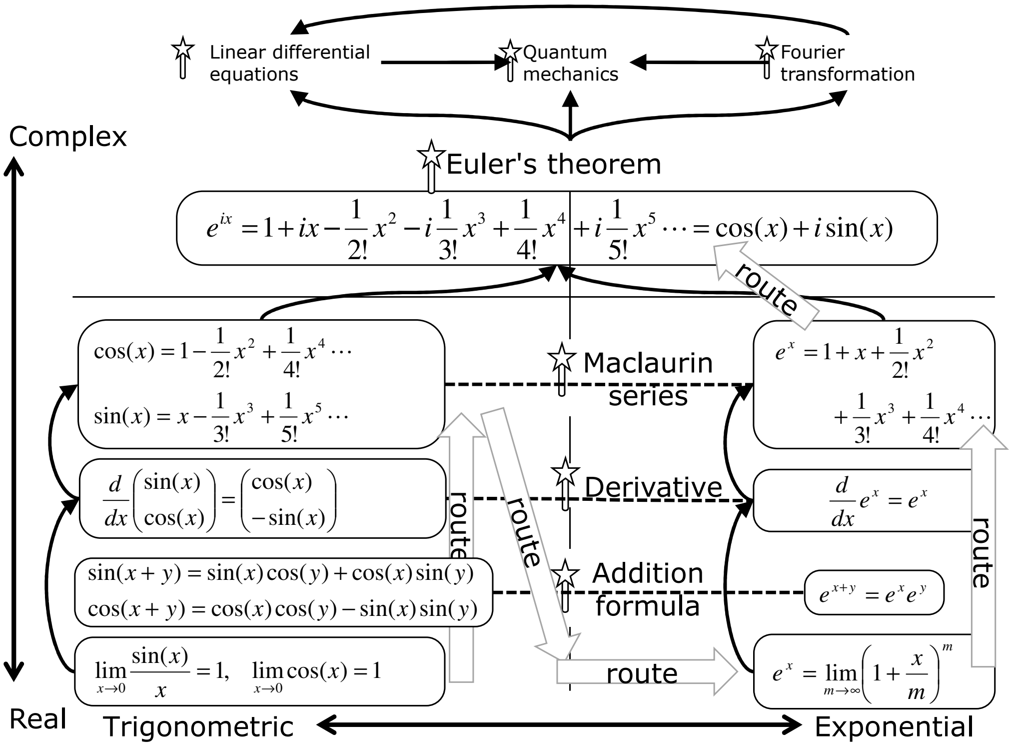


Figure 6. An example of "what" map for Euler's theorem. This map shows that the similarity between the trigonometric and exponential function unifies as a complex function.

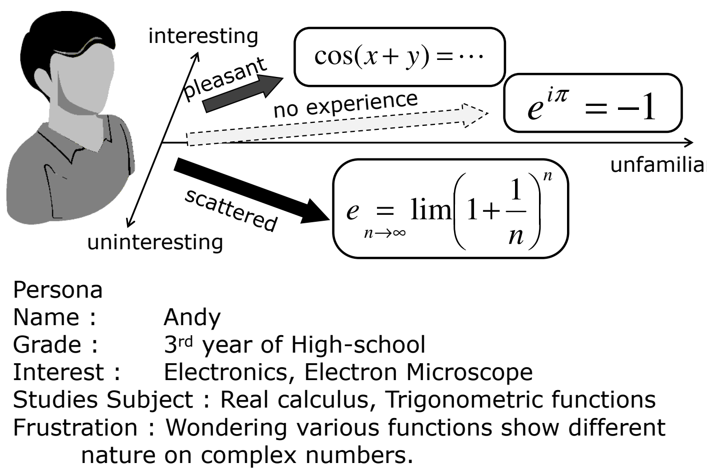


Figure 7. An example of "where" map for Euler's theorem.

4.2 Case 2: Hawking Radiation as Quantum Tunneling

Next, our route map describes a more practical and complex educational content, the famous "Hawking radiation" from black holes. Hawking radiation is the phenomenon in which a black hole emits radiation from its event horizon if quantum effects are considered. The original paper by Hawking [8] seems difficult for undergraduate students, but an understandable explanation of Hawking radiation based on the quantum tunneling effect has been proposed [20]. According to this quantum tunneling explanation, it is feasible for undergraduate students to obtain the energy distribution of Hawking radiation using quantum mechanics, analytical mechanics, and general relativity. This is a good case for teaching the relation and application of these theories.

An example of our "what" map of Hawking radiation as a quantum tunneling effect is illustrated in **Figure 8**.

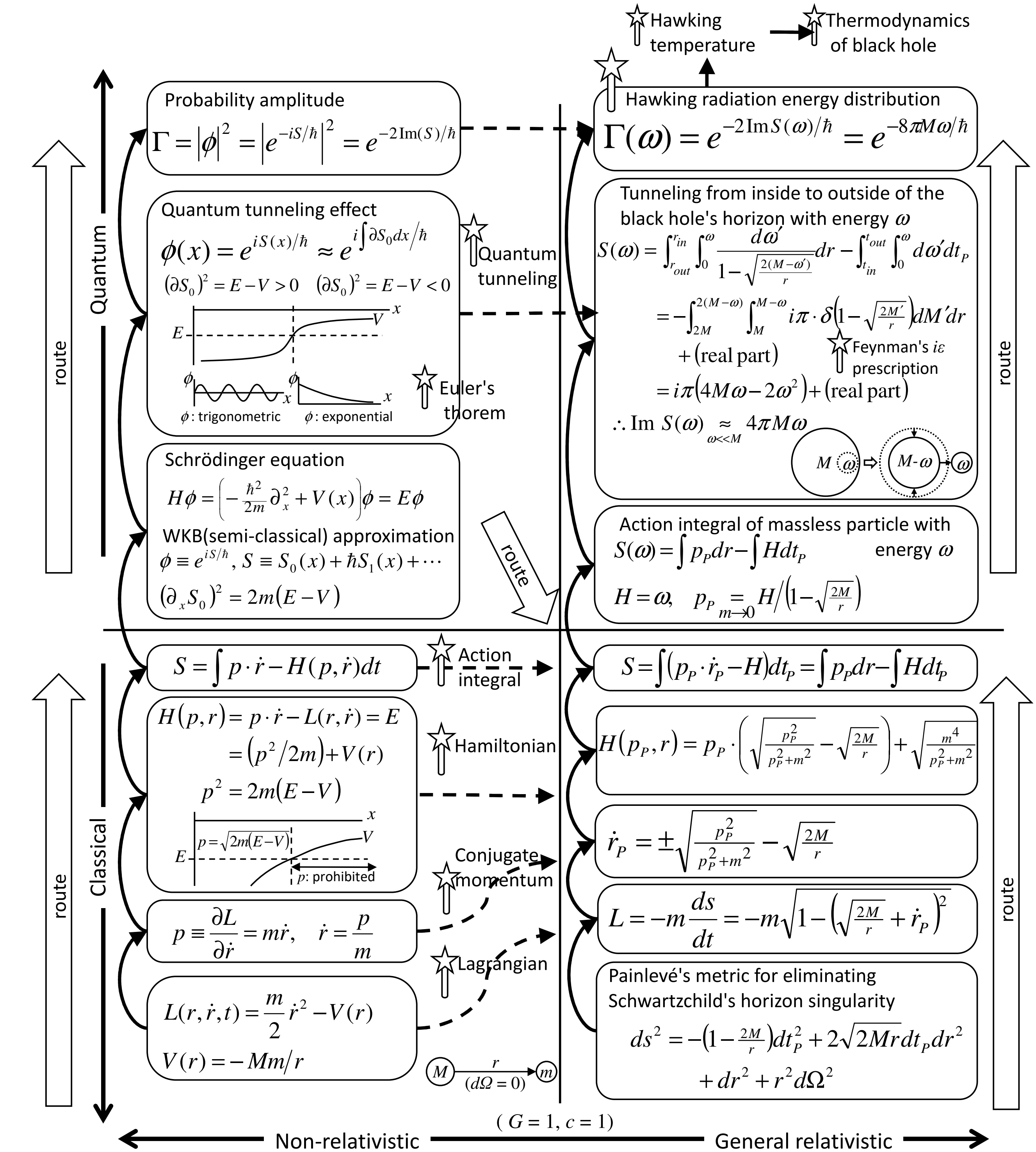
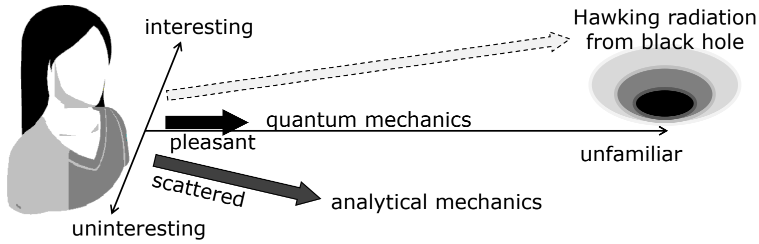


Figure 8. An example of "what" map for Hawking radiation. This map shows that the auxiliary steps by non-relativistic theories (left) support the corresponding general-relativistic quantum tunneling (right). (Here, the variables *t, x*, *r*, and *p* represent time, *x*-directional and radial positions, and their conjugate momenta, respectively. The ∂_x means partial derivative $\partial/\partial x$, and $\dot{x}$ is the time derivative of *x*. The subscript *P* in variables t_P , r_P, and p_P indicates that they are in the Painlevé coordinates. The functions represent that $L(x, \dot{x})$ is Lagrangian, $H(p, x)$ is Hamiltonian, $S(x)$ is the action integral, $\phi(x)$ is Schrödinger's wave function, Γ is the probability amplitude, and $V(x)$ is the potential energy at position *x*. The *M* and *m* are the mass of black hole and the mass of the particle, respectively. The *E* shows the total energy of the systems, and ω is the energy of the massless particle emitted from the black hole. The constants *G*, *c*, *h* are the gravitational constant, the speed of light, and Planck constant ($\hbar = h/2\pi$), respectively. To simplify, a system of units is chosen in which *G* and *c* are equal to 1.)



Persona
Name : Beth
Grade : Undergraduate 2^{nd} year
Interest : Astronomy, Cosmology
Current subject : Quantum mechanics I, Introduction to Relativity
Studied Subject : Analytical Mechanics I,II
Pleasure : Reading on Stephen W. Hawking
Frustration : Level gaps between studied courses and famous theories.
How useful studied courses to understand the famous theories?

Figure 9. An example of "where" map for Hawking radiation.

The "what" map has a frame with non-relativistic vs. general relativistic and quantum vs. non-quantum (classical) axes.

The mathematical details will not be explained. The relativistic elements for Hawking radiation on the right side are almost the same as those in the referenced paper [20]. Correspondingly, the elements of undergraduate-level quantum and analytical mechanics are placed in the non-relativistic area on the left.

The lower districts of "what" map show the corresponding structures of non-relativistic (left) and general relativistic (right) classical mechanics. In the lower right, the action integral S and the Hamiltonian H near the event horizon of a particle with mass m are obtained.

The upper districts show the corresponding structures of the non-relativistic (left) and general relativistic (right) quantum tunneling effects. In the upper left district, the probability amplitude Γ of a particle with energy E appearing by quantum tunneling through the potential V is calculated from the imaginary part of the action integral S.

In the upper right district, the Hawking radiation (the probability amplitude Γ of a massless particle with energy ω tunneling out side the horizon of the black hole) is similarly obtained from the imaginary part of the general relativistic action integral S.

Correspondence with non-relativistic elements (left) and general relativistic elements (right) is indicated by dashed links and landmarks.

Figure 9 shows a "where" map for this example. The content is similar to that in Case 1. The route selection in the "what" map will be based on the content of the "where" map, including this persona and her experience level.

Thus, the experiences root map enables the sharing of a "what" map with students as a structured guide map of subject and topic content in STEM education. Furthermore, the "where" map is created by categorizing students' information and characteristics as personas, which are then reflected in the route design in the subject accordingly.

5. CONCLUSIONS AND REMARKS

We proposed an experience route map that consists of "what" and "where" maps. The "what" map identifies the structure of the knowledge network that should be understood. The "where" map assists us in determining the best route for the learner in the "what" map. Furthermore, sharing the "what" map with students as a guide map is expected to mitigate the comprehension lag, which leads to missed the opportunities in courses, low motivation, or fall out during the course, as illustrated in **Figure 1**.

Here, we remark on the application of our approach to faculty development. A faculty member could use route mapping to design the syllabus and implement the course lecture. The "what" map helps a faculty member clarify both the content structure of the syllabus and the target students learning experience along the route. Furthermore, sharing the "where" map with each type of student encourages faculty to consider having a common understanding with students about what they study and the pain points that they face that are difficult to understand. Each "where" map may be thought of as an alignment diagram [13][14] for each type of student.

In addition, we note on our experience route mapping and student diversity. There is more than one type of student within a classroom. They have different interests and different experience levels. In such a case, we extract several types of personas and "where" map by a survey. These different variants of persona and "where" map assists faculties to design different routes in the "what" map for responding to heterogeneity within students. In **Figure 10**, we illustrate that the combination of the "what" and "where" maps help faculties adapt to student diversity.

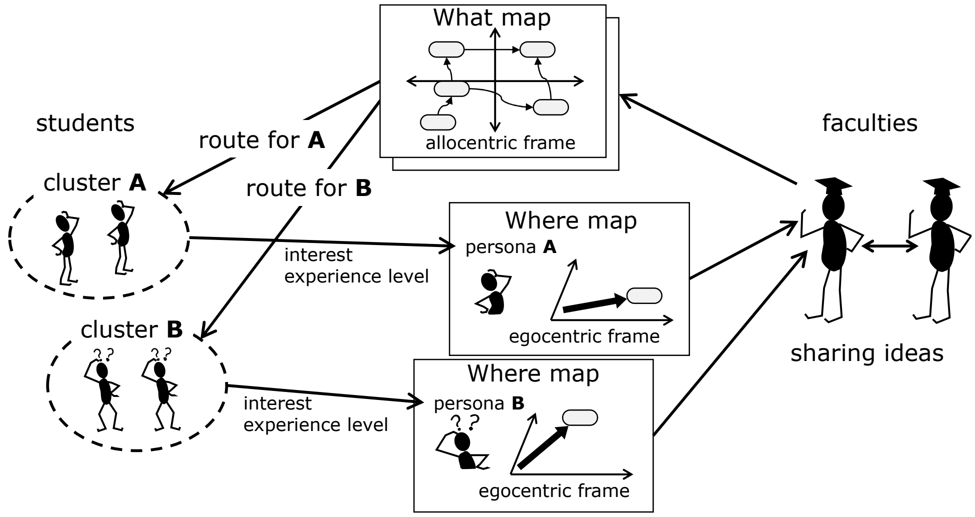


Figure 10. The combination of the "what" and "where" maps assist faculty members to adapt themselves to students' heterogeneity and to share their ideas on syllabus design.

This study is still only theoretical. The validity of this idea relies on analogies from the results of previous research. Future tasks will include the implementation protocol of persona and "where" map making, field application, and empirical research.

6. ACKNOWLEDGMENTS

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